University of Alberta

The Economics of Wetland Drainage: A Case Study in Canada's Prairie Pothole Region

by

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Abstract

This research project estimated on-farm costs and benefits associated with wetland drainage in east-central Saskatchewan. A Monte Carlo simulation was used in conjunction with NPV analysis to examine the economics of drainage for a representative farm in the study area. The main objectives were to determine the economic feasibility of drainage, ascertain the value of drained lands to farm operators, and assess the risk of further wetland loss in the region.

Findings indicated that surface drainage projects conducted by farm operators are economically feasible and that future wetland loss can be expected in the study area. An estimate of about 35%-40% of remaining wetland area is potentially at risk of drainage. Public policy solutions would be necessary to arrest further wetland declines. Potential incentive payments, one of several policy instruments that could be used for wetland conservation, are estimated in this analysis.

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Chapter 1: Introduction

1.1 Background

Wetlands are described as transitional environments between their terrestrial and aquatic counterparts (Bardecki, 1989). Many of them will only hold water for portions of the year, often during times of excess moisture. They are distinguished from terrestrial environments by their ability to support aquatic plant and animal life (Huel, 2000). Several unique ecosystem functions that society highly values are associated with wetlands.

According to Jon Krutilla in Goldstein (1971, preface), "wetlands provide a classic case of conflict in resource utilization." Wetlands that are present in agricultural regions become areas of productive farmland once drained and are nuisances in their natural state that can result in substantial increases in costs of agricultural production (Danielson and Leitch, 1986). The disadvantages of wetland areas for farm operators encourage conversion to cropland (Goldstein, 1971). At the same time wetlands are an integral part of the natural ecosystem and provide social values in the form of habitat for species such as waterfowl, improvements in water quality, flood protection, and amenity values such as recreation (Scodari, 1990; Lupi Jr. et al., 1991). Wetland drainage by farm operators may have an adverse impact on society through the loss of these values.

Conversion of wetlands to agriculture has historically been the leading cause of wetland loss in North America (Bardecki, 1984; Lynch-Stewart et al., 1993). Wetland drainage was often encouraged by governments to promote economic growth (Danielson and Leitch, 1986; Douglas, 1989). When society began to realize the value of wetlands, most direct subsidies for drainage activities were removed and policies began to appear that were designed to protect wetlands. However, drainage of wetlands for agricultural purposes continues since wetlands provide few benefits that accrue to farm operators (Bardecki, 1987). Due to the low private value of wetlands, incentives are biased in favor of more drainage than would occur if all benefits and costs, private and social, were considered in wetland use decisions (Goldstein, 1971). Many wetlands are still at risk of conversion for this reason.

1.2 Economic Problem

Converting wetlands to agriculture is a means for farm operators to expand their cultivated land base and increase private returns. The additional agricultural output provides benefits to society in the form of additional food resources. However, if the value of the goods provided by the wetland is greater than the value of the additional food resources, society experiences a net loss. It is important to quantify these economic trade-offs to determine the optimal use of a wetland resource.

There exists an extensive body of literature pertaining to wetlands. Much of the research on wetlands has been conducted recently since prior to the latter part of the last century wetlands were believed to possess no value to society (Turner et al., 2003). Although drainage for agricultural purposes has been conducted for hundreds of years, much of the research into the benefits of wetland drainage coincided with large increases in commodity prices experienced in the 1970's as farm operators tried to expand their cultivated land base. Removal of wetlands was seen as a means of bringing more land into production and considerable drainage was conducted during this period. It was not until the 1980's that researchers began seriously addressing the issue of wetland loss. Studies have focused primarily on identifying and valuing wetland functions; determining the economic feasibility of drainage for private landowners; comparing social versus private benefits and costs of wetland drainage; and developing programs to reduce wetland loss.

Despite considerable research on wetlands, several gaps and limitations remain. Most research in this area focuses on drainage projects that require capital investments in drainage infrastructure by farm operators or governments. Private projects studied are either subsurface drainage projects that require installation of drainage tiles (van Vuuren, 1994; Danielson and Leitch, 1986), or surface projects that require construction of deep drainage ditches (Myhre, 1992). Engineered drainage systems, often comprised of a large network of canals for use by farm operators, are those funded by governments (Cecile et al., 1985; Rigaux and Singh, 1977). The type of drainage studied in this analysis however, represents less intensive surface projects conducted by the farm operator through the use of their own equipment. The projects studied in much of the literature are larger-scale efforts often carried out by specialized drainage firms.

The studies that scrutinize the economic implications of drainage calculate the economic feasibility of wetland drainage by comparing benefits received from increased crop revenues to the costs of the drainage system. Such studies may not be including all the benefits farm operators receive from removing wetlands from their fields. Therefore, the results may only estimate a lower bound of the benefits a farm operator receives from drainage. An important factor in drainage decisions, costs incurred through maneuvering around wetlands, is often discussed but never quantified. Leitch (1983) noted that farm operators were willing to remove wetland obstacles from fields even when it did not appear economically feasible to do so using increased crop revenues as the sole benefit from drainage. These additional costs are generally not included in research because of their field specific nature. The present study attempts to incorporate these costs into the analysis.

Another component of the present analysis that has not been addressed previously is the time a farm operator has available for drainage projects. Since this study is analyzing drainage projects being undertaken directly by the farm operator, availability of time is an important consideration. Other research, such as McColloch and Wissman (1988), assumed that all drainage occurs in the first year of the analysis. This assumption could increase the returns to drainage, making it appear more attractive than it would be if drainage occurred over several years. Adding time to the analysis will provide economic outcomes closer to those actually experienced by farm operators in the study area.

1.3 Research Problem and Objectives

The purpose of this study was to analyze the economics of surface drainage projects in east-central Saskatchewan. The specific objectives of the study were threefold: (1) to determine the economic feasibility of wetland drainage for a representative farm in the study area, (2) to estimate the value of drained lands to farm operators, and (3) to assess the risk of further wetland loss in the region. The focus was not to promote wetland drainage, but to determine whether or not wetland drainage was a rational decision for farm operators. The value of drained lands to farm operators determined through the analysis facilitated the estimation of potential incentive payments that could be used for wetland preservation. However, incentive payments are only one of a host of policy instruments that could be used to conserve wetlands. Successful wetland conservation programs could be developed that do not require the use of incentive payments.

The benefits and costs incurred by farm operators that drain wetlands were quantified using capital budgeting techniques in conjunction with simulation analysis. Monte Carlo simulation was used to calculate private drainage returns in the form of cash flows. Cash flows were then analyzed in a net present value framework. The use of net present values facilitated discounting over time. The study determined whether surface drainage is economically feasible by comparing the discounted cash flows for a farm that expanded its cultivated land base through the use of drainage relative to maintain its existing farm size. The present value of ending wealth for the two alternative actions was compared to determine whether investment in drainage improved farm performance.

Many factors beyond a farm operator's control that impact farm performance were included in the model as stochastic elements. These variables were weather, crop yields, commodity prices, and the time farm operators could devote to drainage activities. Several scenarios are presented relating to the economics of drainage and its implications for wetland conservation along with sensitivity analyses to emphasize the impact of key variables. Summary outputs were used to draw conclusions that pertained to the research objectives of the present study.

1.4 Organization of the Study

The following chapter, Chapter 2 provides background on issues pertinent to the research problem addressed by this thesis. Literature relating to the problem of wetland loss is examined in this chapter. The chapter begins with a discussion on wetlands and the importance of maintaining wetlands in their natural state. Statistics on the severity of the wetland drainage problem and policies used to protect them are also presented. Following this is an overview of agricultural drainage projects and the benefits and costs realized by farm operators through drainage. The role that agricultural policy has played in drainage decisions is also discussed. The chapter ends with a review of several studies that address the conversion of wetlands to agricultural purposes. The synthesis of this existing literature provides an indication of the complexity of the problem, the issues that surround it, and provides insight into performing wetland drainage research.

Chapter 3 opens with an overview of the region in which the study area resides, the Prairie Pothole Region, and the importance of wetlands within it. The chapter then presents information regarding drainage in Saskatchewan and data specific to the study area. The description of the study area provides a background on agricultural production and drainage activity in the region and this information was incorporated into the analysis.

The fourth chapter introduces the modeling techniques and economic theory used for this research. Net present value analysis and Monte Carlo simulation were used in the analysis. The chapter then describes the resulting basic model structure and the components incorporated into the analysis.

Chapter 5 provides a detailed discussion of the empirical simulation model. It describes the components of representative farm used in the analysis. The chapter then discusses the stochastic components estimated, economic relationships calculated, farm programs utilized by the representative farm and how drainage and drainage decisions were modeled. Chapter 5 concludes with an overview of the scenarios and sensitivity analyses performed and a discussion on the summary statistics used to draw conclusions. In the sixth chapter, model results for each scenario and sensitivity analysis are presented along with a discussion of the results.

Chapter 7, the final chapter, presents conclusions that were drawn from the results. Conclusions relate to the economic feasibility of drainage, the potential for wetland loss in the study area and implications for wetland conservation. Model limitations and further research possibilities are also discussed.

Chapter 2: Wetlands and Agriculture

This chapter provides an overview of the issues and previous research relevant to the present study. The main purposes of the chapter are to identify important factors pertaining to wetland preservation and agricultural drainage that need to be included in the analysis, and demonstrate the need for this research. The chapter describes what wetlands are, the values they possess, and the relationship between wetlands and agriculture. Conservation of wetlands is important because wetlands possess value in their natural state. On the other hand, conversion of wetlands to agricultural land provides income generation opportunities for farm operators. Determining the allocation of wetlands between these two competing uses is difficult. Researchers have been addressing this problem for over thirty years. However, previous studies have limitations because of the complexity of the problem and the issues that surround it.

2.1 Wetlands

This section addresses the importance of wetland conservation and the difficulties encountered in maintaining wetland resources. Research has shown that wetlands are unique ecosystems and several functions have been identified that provide significant benefits to society. Despite these benefits, wetlands continue to be converted to other uses. Explanations for continued wetland drainage and future implications of these wetlands losses are presented. This is followed by a discussion on economic theory relating to wetland conservation and policy instruments used to maintain these valuable resources.

2.1.1 What is a Wetland?

Although there is no internationally accepted definition of a wetland, they can simply be described as transitional environments that are neither wholly terrestrial nor completely aquatic (Bardecki, 1989)[1]. The term "wetland' encompasses bottomlands, marshes, bogs, potholes, swamps and tundra (Stavins, 1990; Scodari, 1990). The formal definition used by the United States Army Corps of Engineers (the body officially charged with the responsibility of most Federal river and harbor projects in the United States) as well as the Environmental Protection Agency, the United States Fish and Wildlife Service and the United States Soil Conservation Service, characterize a wetland as an area where the soil is saturated or covered by shallow water at some time during the year and the soil is saturated long enough to grow aquatic vegetation (Scodari, 1990). The problem with defining a wetland arises from their dynamic character, which makes it difficult to define their boundaries (Mitsch and Gosselink, 1993). Brouwer, et al. (2003, p. 52) note that "the flows into and out of wetlands are extremely variable and stochastic in nature."

2.1.2 Wetland Values

The majority of wetland values can be grouped into four main categories: habitat, amenity, water quality, and hydrologic (Lupi Jr. et al., 1991). Wetlands are home to a wide diversity of flora and fauna that depend on wetland habitats for survival; therefore, they are often home to rare or endangered species (Hursin, 1991). Wetlands are nurseries for many species of sport fishes (Heimlich et al., 1998). Amphibians, reptiles, waterfowl, and fur-bearing animals such as moose, muskrat, beaver, otter, mink and raccoons also depend heavily on wetland habitats (Heimlich et al., 1998). Viewscapes, open spaces, education and recreation values are amenity values provided by wetlands (Lupi Jr. et al., 1991; Scodari, 1990). Wetlands enhance water quality through sediment and nutrient storage and therefore can be used for water purification and treatment of human wastes (Scodari, 1990). Hydrologic values include flood water storage, erosion control and prevention, and groundwater recharge and storage (Scodari, 1990; Stavins, 1990).

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[1] There are over 50 wetland definitions in use (Dugan, 1990).

Wetlands also provide climatological stabilization and assist in nutrient cycling (Douglas and Johnson, 1994). Huel (2000) indicated that wetlands affect weather through, for example, impacts on local rainfall. However, these wetland functions are extremely complex and poorly understood; thus their valuation is difficult (Douglas and Johnson, 1994). Research also provides the potential to discover new goods and services that wetlands may provide such as future medicines (Scodari, 1990). No values are assigned to these goods and services because their potential benefits are unknown.

2.1.3 Wetland Valuation

Even though wetlands have been described as the most biologically productive ecosystems in the temperate regions, the goal of wetland valuation is not to develop an associated price, but merely to facilitate comparisons between the values of wetland functions and proposed alternative uses (Mitsch and Gosselink, 1993; van den Bergh, 1999). If governments are going to make decisions to maximize social welfare, then wetland valuation becomes important (Taff, 1992).

There is considerable heterogeneity among wetlands; each wetland can provide various levels of different goods and services, and some may not provide certain goods and services at all. This heterogeneity, along with geographic and demographic variations in demand lead to a wide range of estimates for wetland values (Stavins, 1989). The greatest difficulty in wetland valuation, however, is a lack of knowledge of how wetland characteristics interact to produce wetland goods and services and how development within wetlands impact these characteristics (Scodari, 1990). As wetlands become scarcer, their marginal value will increase (Cecile et al., 1985).

Several relatively simple methods for valuation exist: market analysis, productivity losses, production functions, public pricing, damage costs avoided, defensive expenditures, relocation costs, replacement/substitute costs, and restoration costs (Turner et al., 2003)[2]. More rigorous empirical valuation techniques include: the contingent valuation method, travel cost models, and hedonic pricing (Stavins, 1990)[3]. Although these methods are well developed, each method has conceptual problems that researchers need to consider when using them in valuation (Boyle, 2003; Parsons, 2003; Taylor, 2003). The choice of valuation method used will depend on why the information is needed and the types of values that are being measured (Taff, 1992).

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[2] See Appendix A for a brief description of these valuation methods.

[3] The contingent valuation method is a survey technique where consumers are asked their willingness to pay for a good or service through the use of hypothetical market transactions and treats the decisions of respondents as values which may exist for the good or service (Thomas et al., 1979). In Cooper (1995, p.4) the travel cost method is one that "uses travel costs to a recreational site as a proxy for the price of the trip and the number of trips to the site as quantity to statistically estimate a demand curve for the site." According to Turner et al. (2003, p. 89) "hedonic pricing derives an implicit price for an environmental good from an analysis of goods for which markets exist and which incorporate particular environmental characteristics."

Numerous studies have been conducted that assign monetary values to the various wetland goods and services. Little research, however, has been conducted in Canada. The most comprehensive studies of wetland values are a meta-analysis of wetland valuation research conducted by Brouwer et al. (1999) and an Economic Research Service Report developed by Heimlich et al. (1998)[4]. The Brouwer et al. (1999) study compared the results of 30 different contingent valuation studies in temperate climate zones in developed economies for four types of wetland goods and services: flood control, habitat, water quality and groundwater recharge. These goods and services pertain to three of the four wetland categories defined earlier (habitat, amenity, hydrologic, and water quality). The only category not represented was amenity values. The findings for the studies analyzed indicated that flood control generates the highest mean willingness-to-pay (WTP) followed by wildlife habitat provision, water quality and groundwater recharge at approximately $138.75, $114.15, $78.75 and $32.25 (1995 USD) per household per year, respectively[5]. They also found that North Americans have higher willingness-to-pay values than Europeans.

The variability in wetland values that arises from utilizing the various valuation techniques, wetland heterogeneity and valuation of different functions is illustrated in Heimlich et al. (1998). Thirty-three studies are summarized representing all goods and services provided by wetlands and numerous different valuation techniques. The majority of the studies are conducted in the United States, but studies from Canada, Austria, Sweden, Australia and other countries are also included. The mean value for life support of marketed aquatic goods varied from $17.30/ha in Florida for blue crabs to $108,545/ha in Australia for fish harvesting. Non-marketed habitat and recreation values ranged from $45/ha for duck hunting in Saskatchewan to non-user fish and wildlife habitat estimates of $858,779/ha in California. Estimates of ecological functions begin at $2/ha for wastewater treatment in Louisiana and reach $496,649/ha for water supply in Massachusetts. Olewiler (2004) also found waste treatment of phosphorous and nitrogen by wetlands in British Columbia's Fraser Valley to be worth between $452-$1,270/ha.

2.1.4 Wetland Loss

Most wetland losses are the result of deliberate human actions, although wetlands do disappear naturally through changing weather patterns. Wetland loss because of direct drainage has been severe in many regions of the world and agricultural drainage accounts for the vast majority of these losses. The following statistics indicate the severity of the problem in North America historically. The agricultural region of the Canadian Prairie Provinces lost over half, approximately 1.2 million hectares, of pre-settlement wetlands by 1976 (Lynch-Stewart et al., 1993). About 68% of original wetland area has been drained in southern Ontario and agricultural drainage accounts for about 85% of this loss (Bardecki, 1984; Lynch-Stewart et al., 1993). In the United States, it is estimated that of the 90 million hectares of wetlands that existed at the time of European settlement, only 50 million remain (Heimlich et al., 1998). Again, about 80% of this wetland drainage was estimated to have been for agricultural purposes. Much of the rest of the world has experienced similar patterns of wetland loss (Dugan, 1990).

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[4] Meta-analysis is defined as "the statistical evaluation of the summary of findings of empirical studies, helping to extract information from large masses of data in order to quantify a more comprehensive assessment" by Brouwer et al. (1999, p. 48). They add that it enables researchers "to explain differences in outcomes found in single studies on the basis of differences in underlying assumptions, standards of design and/or measurement" and "identify criteria for valid environmental transfer or to test the convergent validity of the estimates."

[5] Willingness-to-pay is defined as "the economic sacrifice in terms of income or other goods a person is willing and able to forgo to gain or maintain a resource, good, or service (Cooper, 1995, p. 2)."

Direct drainage of wetlands is the most observable loss of wetlands; however, wetlands are also degraded and destroyed through a number of other human actions. Degradation occurs through acidification, over-consumption of groundwater, contamination from pollutants and chemicals, and eutrophication from high levels of nutrients and sediments (Heimlich et al., 1998; Turner et al., 2003). Chemical and nutrient contamination may be the result of agricultural runoff from cash crop and/or large livestock operations. Agricultural operations also often burn, clear, graze, mow, and cultivate wetland margins and partially dry wetland basins (Brace and Pepper, 1984; Hursin, 1991)[6]. These activities can significantly impair wetland functions and the benefits they provide. Drainage will also destroy connectivity between remaining wetlands and impair habitat and hydrological functions.

2.1.4.1 Why are Wetlands Lost?

Until the latter part of the twentieth century, wetlands were traditionally regarded by society as having very little, or even negative value, and were described as wastelands or sources of disease (Turner et al., 2003). The perception that wetlands possessed no value society encouraged conversion to alternative uses. Research that began to change this perception included the classic work by Hammack and Brown (1974). This study sparked numerous other research regarding wetlands and their value to society. The Hammack and Brown (1974) study discussed how waterfowl are dependent on wetlands and how hunters of migratory ducks value their hunting privileges. They determined that wetlands do possess value in their natural state and need to be conserved because waterfowl production is dependent on suitable wetland habitats. However, even today there is still a lack of understanding of wetland functions and this is one reason why they continue to disappear (Hursin, 1991).

Differences between values that wetlands provide to society and those that can be realized by private individuals also encourage wetland drainage[7]. From a private individual's perspective, a wetland often possesses little value. Private benefits are limited since most of the benefits of wetland conservation accrue to society as a whole and are therefore public goods. This public good nature of wetland benefits often means that these benefits are not accurately priced in the market (Bardecki, 1987). The landowner receives low economic rents from these benefits, even though they bear the costs of wetland ownership such as taxes (Bardecki, 1987). The few wetland income generation opportunities that are available for private individuals include managing them for crops, timber, fur, or grazing, and fee-based recreation (Stavins, 1990)[8]. Other wetland benefits such as flood control and waterfowl production are external to the property rights of the landowner and they are not able to extract payment for providing them (Bardecki, 1989; van Vuuren and Roy, 1993)[9].

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[6] Canadian Wildlife Survey results indicated that 61.4% of wetland margins across the Canadian prairies were impacted by these types of activities between 1981 and 1983 (Brace and Pepper, 1984). Turner et al. (1987) found that 54.5% of wetland margins and 79.2% of basins were degraded in this manner during a 5-year period between 1981 and 1985 across the Canadian prairies. Temporary wetlands experienced greater incidence of impacts.

[7] Social benefits/costs are additions/subtractions to the real national output regardless of the recipient/payer, while private benefits and costs are only those that the owner receives/pays (van Vuuren and Roy, 1993). Differences between the two arise from market imperfections, such as tariffs and export subsidies, taxes, and direct subsidies to production (Willis et al., 1988).

2.1.4.2 The Problem of Wetland Loss

One of the main problems with wetland drainage is that once the land has been drained, it may be impossible to restore the wetland to its original state as changes in the hydrology of the area normally prevents restoration (Mitsch and Gosselink, 1993). The complexity of wetland environments also makes it difficult to understand wetland functions and this leads to problems when it comes to replicating these functions (Kusler, 1990). Therefore, society may still incur a loss when drained wetlands are replaced with created or restored wetlands because these wetlands may only provide a few of the benefits provided by their natural counterparts.

Studies that have compared created and natural wetlands often find that created ones do not resemble natural wetlands (Campbell et al., 2002). However, poor monitoring of existing and created wetlands is often cited as limiting this research and the amount of time needed for the development of a wetland is not known (Campbell et al., 2002; Kusler, 1990; Mitsch and Wilson, 1996). The time it takes to functionally regenerate a wetland may be so long that wetland loss essentially may be irreversible (Arrow and Fisher, 1974). Kusler and Kentula (1990) find restoration or creation of a wetland that completely duplicates a naturally occurring wetland is likely impossible, although success will vary by the type of wetland and function that are being replicated. Prairie potholes are one type of wetland where some success has been experienced in that restoration may be as easy as filling in a drainage ditch (Hollands, 1990; Huel, 2000; Leitch, 1984). Replication of flood control and waterfowl production are wetland functions in which the probability for success in function recovery is high (Kusler, 1990).

Cumulative impacts are another problem associated with wetland drainage. These impacts are estimated to be significant, though they are difficult to evaluate (Johnston, 1994). The increased use of geographic information systems is helping researchers study and quantify these impacts more easily (Johnston, 1994). Cumulative impacts affect water cycles, groundwater supplies, water quality, flood water storage and wildlife (Huel, 2000). With respect to the water cycle, fewer wetlands reduces the amount of water available for evaporation, which leads to lower precipitation (Huel, 2000). It is difficult to estimate how much wetland area needs to be lost before these functions are significantly impaired. However, Turner et al. (2003) and Johnston (1994) note that initial losses generally have smaller effects on wetland functions than later losses[10]. Brouwer et al. (2003) concluded that initial losses in watersheds where wetlands comprise 10%-50% of the area have little effect on the flood control capability of the system, but losses from areas where wetlands represent less than 10% of the area will have a large effect on this wetland function. Other studies have shown that increased fragmentation of wetland habitats increases the distance that animals must traverse between them and results in the concentration of waterfowl and predators in remaining wetlands, lowering nesting success rates (Brace and Pepper, 1984; Johnston, 1994).

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[8] Under certain circumstances wetland income generating opportunities can provide returns greater than those provided by developed uses such as agriculture. A study by Elliot and Mulamoottil (1992), summarized in section 2.3.1, provides a comparison of returns between natural and developed uses of wetlands. It also may be possible to adapt agriculture to wetland environments rather than force the environment to fit with agricultural practices. A paper by Snyder et al. (1999) investigated the potential of such practices in the Florida Everglades. Hursin (1991) also lists agricultural practices that maintain wetland basins.

[9] A property right is defined as "an entitlement on the part of an owner to a resource or good and where the entitlement is socially enforced" by Turner et al. (2003, p.74).

2.1.5 Wetland Conservation

2.1.5.1 Theory

An excellent overview of economic theory applied to wetland resources is given by Danielson and Leitch (1986). The theory illustrates the difference between social and private value of wetlands and the impact this difference has on "optimal" wetland drainage. This is indicated graphically in Figure 2.1 taken from Danielson and Leitch (1986). In the graph, MPC represents marginal private costs; MSC is marginal social costs; MC is total marginal costs and is the sum of the MPC and MSC curves; and MPB represents marginal private benefits. For ease of illustration, the graph assumes wetlands are homogeneous in all respects except for the cost of drainage. Marginal private costs are assumed to be increasing because the least costly wetlands are drained first. The assumption of homogeneity of wetlands yields a linear marginal social cost curve. Marginal private benefits represent the benefits to the landowner from draining an extra hectare of land and are assumed to be linear for simplicity. A private landowner will continue to drain land until MPC=MPB for an optimal level of drainage at X*. Total private net benefits are therefore the area below the MPB and above the MSC curve. The graph indicates that a social cost occurs at the X* level of drainage and that the optimal level of drainage from society's perspective would occur at X**, where MC=MPB. At X**, the loss of public value attributable to wetlands is considered in addition to private costs.

Incentives necessary to persuade farm operators to drain at the social optimal level (X**) can also be gleaned from Figure 2.1. These incentives are entirely a function of the landowner's returns from drainage and are independent of the value of wetlands to society. According to Danielson and Leitch (1986), incentives should reflect the monetary benefits of drainage. The value of these benefits is represented by the area f'ee' on the graph. If landowners were only to drain the social optimal level (X**) of wetlands, then they would be forgoing the additional positive returns to drainage associated with the area beneath the MPB curve and above the MPC curve between the private optimum and the social optimum (X*-X**). Private landowners, however, may demand higher or lower payments because of non-monetary considerations. For example, landowners who enjoy bird watching may accept lower payment. At X**, social costs decrease by the area represented by f'fee' (recall that the MC curve is the sum of the MSC and MPC curves and the area beneath the MC curve and above the MPC curve would represent the increase in social costs in moving from X** to X*) and there is a net social gain of ff'e (f'fee'-f'ee'). The change in expected private returns (f'ee') represents a possible lower bound for incentive payments and the change in social costs (f'fee') is the upper bound. Society could offer landowners area f'fee' before wetland preservation is not in society's best interest. The main difficulty in applying the theory is the difficulty in estimating public benefits, which makes it difficult to determine the social optimum (Heimlich et al., 1998).

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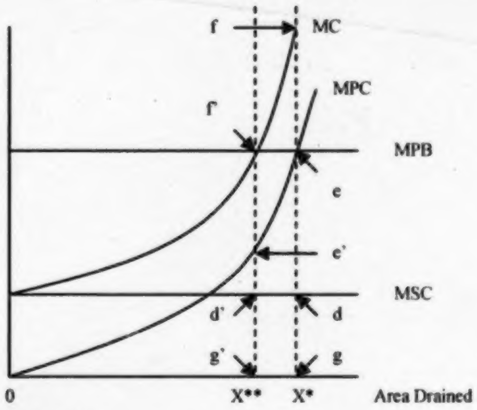
[10] These are referred to as threshold affects by Heimlich et al. (1998).

Figure 2.1 – Comparison of optimal drainage levels using social and private costs



Source: Danielson and Leitch (1986)

2.1.5.2 Wetland Policy

The distribution of wetlands between conversion to other uses and preservation would, as stated by Goldstein (1971, p.1) "be automatically and optimally distributed if the situation were purely competitive and free of characteristics which cause market failures." Market imperfections, such as tariffs and subsidies, and the public good nature of wetlands prevent the optimal allocation of wetland resources (Goldstein, 1971; Willis et al., 1988). Economic theory suggests that when there are externalities, the private market will under or overprovide them (Leitch, 1983)[11]. With respect to wetlands, wetland goods and services will be underprovided in a private market because landowners tend to only take into account the benefits and costs that they receive or incur when making land use decisions (Bardecki, 1989; Danielson and Leitch, 1986; van Vuuren and Roy, 1993). Even if social benefits were considered when making land use decisions, private net benefits often exceed those from preservation (Bardecki, 1987; van Vuuren and Roy, 1993). Therefore from a landowner's perspective draining wetlands is a rational decision even though society may incur a net loss as a result . It is because of this dichotomy between the most beneficial use of wetlands to society and private individuals, and the fact that the majority of inland freshwater wetlands are controlled by private landowners, that market mechanisms are likely to fail in optimally allocating wetland resources between conversion to other uses and conservation (van Vuuren and Roy, 1993; Goldstein, 1971)[12]. Public policy solutions, therefore, become necessary.

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[11] Leitch (1983, p. 1469) defines externalities as "unintended effects of production or consumption activities that are felt by parties not directly involved."

With increased understanding and awareness of wetland values, wetland policy has shifted from promoting drainage to promoting conservation of existing wetlands and encouraging wetland restoration, creation and mitigation[13]. Wetland creation, restoration and mitigation policies are emerging to restore wetlands and improve wetland functions in areas where drainage activity has historically been high. These policies are necessary because developed wetlands will not usually revert back to their natural state on their own.

According to Turner et al. (2003, p. 73) wetland protection is "associated with opportunity costs, which are the benefits forgone from possible alternative uses that are essential to continued wetland functioning". Several types of policies are used to promote protection of wetlands. These include: economic measures, regulations, voluntary programs and land purchases (Nelson, 1986). Most of these policies have traditionally been used to protect existing wetlands. However, the same approaches are used for wetland creation, mitigation and restoration (Goldsmith and Clark II, 1990). Each type has its advantages and disadvantages, although protection is more effective if a mix of the different policies is utilized (Goldsmith and Clark II, 1990; Nelson, 1986). Nelson (1986) also states that wetlands with outstanding ecological and aesthetic values at risk of conversion require greater levels of protection through the use of strict regulatory measures, while protection of wetlands without such values should be based on their values to agriculture or other drained uses versus their value in their natural state.

Economic measures can be incentive payments to landowners to conserve wetlands. These payments help defray the costs of wetland ownership, but critics of economic incentive programs state that the use of these instruments results in payments being made to landowners who never intend to drain their wetlands (Hursin, 1991). Programs that use incentives include property tax credits and exemptions, licensing and lease agreements, and conservation easements (Goldsmith and Clark II, 1990; van Kooten and Schmitz, 1992). These programs vary with respect to the amount of control the landowner maintains over land use decisions. For example, some agricultural programs allow for limited agricultural use, such as haying or grazing, while others allow none. Higher incentive payments are offered to landowners who enter into longer term agreements, conserve larger areas of land and/or forgo all use of the land (van Kooten and Schmitz, 1992).

With respect to conversion of wetlands to agricultural uses, farm subsidies can impact the use of economic measures for wetland conservation. In many developed countries, farm profits are heavily subsidized and economic incentives must also compensate farm operators for forgone subsidy payments (Willis et al., 1988). Therefore, it may appear as though conservation is expensive when it is actually agricultural protection that is the problem (Willis et al., 1988). On the other hand, cross-compliance is another form of an economic measure where landowners only receive payments under other programs if they maintain wetland resources. The "Swampbuster" provision of the 1985 Food Security Act is an example of such a program in the United States. Under the provision, farm operators that drain wetlands are denied most farm program benefits (Heimlich et al., 1998).

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[12] In the contiguous 48 states, it is estimated the 82% of wetlands and former wetlands are privately owned (Heimlich et al., 1998)

[13] Overviews and analyses of various wetland policies in Canada and abroad are found in van Kooten and Schmitz (1992), Porter and van Kooten (1993), Taylor et al. (1993), Hursin (1991), Heimlich et al. (1998), Campbell et al. (2002), and Turner et al. (2003).

Regulatory measures are restrictions or prohibitions on activities that affect wetlands. All levels of government, federal, provincial and municipal, may be able to use regulatory measures to protect wetlands. Some examples include requiring landowners to obtain permits to conduct drainage and requiring landowners who do drain to either create a wetland elsewhere or invest in mitigation projects (Heimlich et al., 1998; Hursin, 1991). Two disadvantages of regulatory measures are that they may require strict enforcement to be effective, which leads to high program costs (Hursin, 1991; Nelson, 1986). Monitoring and enforcement may also infringe in landowner's property rights (Hursin, 1991; Nelson, 1986). Regulatory measures are often unpopular with landowners because of this (Hursin, 1991).

Voluntary programs rely on the altruism of landowners to maintain wetlands in their natural state. These programs to encourage wetland preservation, mitigation and restoration are often supported through the use of moral suasion, such as pubic awareness, education programs and recognition (Goldsmith and Clark II, 1990; van Kooten and Schmitz, 1992). Voluntary programs have limited effectiveness when used alone, since landowners are not bound to any sort of agreement. However, they can increase the effectiveness of other types of policies. For example, when used in conjunction with economic incentives, voluntary measures may reduce the level of compensation needed and thereby reduce overall program costs or perhaps improve participation rates (Goldsmith and Clark II, 1990; van Kooten and Schmitz, 1992).

When comparing different policy tools, a survey of both agriculturalists and persons interested in wetland conservation conducted by Nelson (1986) indicated that voluntary measures are the most politically feasible, but often the least effective. On the other hand, respondents agreed that regulatory measures and economic incentives are more effective. However, regulatory measures are generally strongly opposed by agricultural groups and as a result are marginally politically feasible (Goldsmith and Clark II, 1990; Nelson, 1986). Annual payments are a popular form of economic incentives. Under such programs, landowners agree not to drain their wetlands in the year the payment is made. Therefore, these types of programs will only provide protection while payments are made to landowners (Goldsmith and Clark II, 1990; Nelson, 1986). Finally, outright purchases of wetlands are viewed as one of the most effective conservation policies, but the expense often precludes its use (Nelson, 1986).

2.2 Agricultural Drainage

In this section, the motivations behind drainage for agricultural purposes are explored. Essentially, agricultural drainage helps farm operators increase profitability and reduces the risks of lower returns caused by excessive moisture (Eidman, 1997). The model developed for the present study incorporates the benefits, costs and types of drainage systems used by farm operators discussed in this section. Regulations and subsidies are also discussed as they may affect whether or not drainage occurs. Farm operators contemplating drainage should consider these factors when determining whether drainage is in their best interests.

2.2.1 Why is Agricultural Drainage Conducted?

The main objectives of agricultural drainage projects are twofold: (1) to remove wetland areas on what would otherwise be productive farm land; and (2) to remove limitations on land caused by wet soils. Drainage projects conducted for the second purpose are called general field drainage projects, and although draining wetland area is not necessarily the primary motivation, wetland loss will often occur (Leitch, 1983). It is wetland loss that results in the controversial nature of drainage (Leitch, 1983).

Agricultural drainage has been conducted for hundreds of years. As early as 1859, there was information available to farm operators on how to improve drainage on their lands (French, 1859; Heimlich et al., 1998). The amount of drainage conducted for agricultural purposes is influenced by several factors including politics, economics, attitudes and climate (Leitch, 1983). Agricultural drainage received much attention in the literature in the 1970's and 1980's. There have been fewer studies since then as the focus of researchers has shifted to conservation of wetlands.

2.2.2 Drainage Systems

Two types of drainage systems are employed, surface and subsurface. Both general field drainage and wetland drainage may utilize either/both surface or subsurface drainage systems. Surface drainage involves the construction of ditches and/or contouring of the land to remove water from the surface of the soil. A farm operator may or may not be able to farm through drainage ditches. Contouring involves enhancing the natural landscape to create pathways for water to travel. Plastic piping, called tiles, are installed under the soil in subsurface drainage. Generally, subsurface drainage is more expensive and durable than surface operations (Douglas and Johnson, 1994). Maintenance of surface systems is necessary to keep the system operational (Manitoba Agriculture, 1985).

Efficient drainage systems often require outlet drains, which remove water from the field (Cecile et al., 1985; Eidman, 1997). These drainage outlets consist of engineered ditches and channelized streams and are generally constructed through the use of public funds (Bardecki, 1987). Outlet drainage works are more important for general field drainage because water can be consolidated and/or used for irrigation in surface wetland reclamation projects if such outlets are unavailable (Rousseau, 1983). Rousseau (1983), however, states that less drainage may occur in areas without drainage outlets as drainage costs may be higher and farmers may experience difficulty obtaining permits to conduct drainage.

2.2.3 Drainage Benefits

The benefits of improving drainage in fields are well documented. Drainage benefits include: improved crop yields from reduced risk from yield loss during wet years, the ability to produce higher value crops, increased hectares under cultivation, more efficient field operations, and increased land values (Wanchuk, 1986; Irwin, 1979; Eidman, 1997; Anthony, 1975).

Increases in crop yields and the ability to switch to higher value crops are most commonly discussed for subsurface or general field drainage projects where wet soils limit agricultural productivity. These benefits arise from better soil aeration, higher soil temperature, better soil structure, lower water tables, and expedited removal of standing water in fields (van Vuuren, 1994; Eidman, 1997)[14]. Higher soil temperatures and expedited removal of standing water in the spring result in earlier planting dates that lengthen the growing season and improve timeliness of field operations; both of which increase yields (Aldabagh and Beer, 1975; Wanchuk, 1986). The improvements in field characteristics allow for more efficient root functions; greater root growth to anchor the plants; improved water and mineral absorption; enhanced synthesis of organic compounds for crop growth and development; and they reduce oxygen deficiency problems (Anthony, 1975). Yield benefits are generally greater in wet years than in drought years (Eidman, 1997). Improving drainage on the poorest drained soil classes typically results in higher returns to drainage because potential yield gains are the largest and there is more opportunity to grow higher valued crops (Kanwar et al., 1983). Increases in yield diminish as the natural drainage capability of the soil increases (van Vuuren, 1994).

Through increased hectares, a farm operator is able to generate revenues from lands where crops were previously not grown and can therefore spread their fixed costs over more acres. Once drained the land is practically indistinguishable from the rest of the producing area and can contain the most productive soils within the field (Wanchuk, 1986). The area drained through drainage is often obtained at well below market rates (Anthony, 1975; Lyseng, 2002).

Wetlands and low spots are obstacles that increase the distance a farm operator must travel in a field resulting in inefficient field operations. These inefficiencies are often referred to as nuisance costs (Danielson and Leitch, 1986; Goldstein, 1971). Drainage reduces the number, size, and duration of wetlands and low spots in fields (Eidman, 1997). Also, low spots that remain wet longer in the spring and become wet more rapidly during rains are less of a problem (Anthony, 1975). Reductions in nuisance costs are the result of fewer turns with machinery, lower risk of equipment becoming mired in fields, reduced wear and tear on machinery, less waste of crop inputs, and a reduction in the need to return to fields and seed low spots (Eidman, 1997; Leitch, 1983). Fewer turns result in reduced time spent in the field by farm operators and cost savings in machinery operating expenses used to travel the extra distance around wetlands and low spots (Accutrak Systems Ltd., 1991). Savings in crop inputs are also realized because fewer areas are overlapped (Accutrak Systems Ltd., 1991). Farm operators may realize significant benefits or cost savings through drainage given that the timing of field operations may be critical in some years because of weather conditions (Aldabagh and Beer, 1975).

Appreciation in land values will reflect increases in productivity that result from drainage. Benefits of this nature may become relevant to the farm operator's drainage decision if the project does not generate positive returns within the planning horizon used in decision making (van Vuuren, 1994)[15]. For example, if the farm operator wanted to sell the land in the next ten years and was contemplating improving drainage on the land, it would be appropriate to include the expected appreciation in land value attributed to drainage in the drainage decision.

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[14] Estimates of increases in yields in the United States attributed to improved drainage systems are provided by Eidman (1997), and Anthony (1975). Indications of how drainage reduced the numbers of years with yield losses are noted in Lyseng (2002) and Pearson and Kulshreshtha (2002).

[15] A hedonic analysis conducted by Palmquist and Danielson (1989) found that draining wet soils would increase land values by 34%, on average, in North Carolina. A 1994 study by van Vuuren also noted that land rents were 97% higher on well-drained soils than on poorly drained soils and 31% higher than on imperfectly drained soils in southwestern Ontario.

2.2.4 Drainage Costs

Capital investments for on-farm drainage systems can include: open ditches, subsurface tiles, pumping stations and contouring (Anthony, 1975). Costs of on-farm systems will vary with the type of drainage used, wetland characteristics, and topography (Danielson and Leitch, 1986). Wetland attributes that affect drainage costs include: depth, durability, ecological characteristics, and whether the wetland is temporary or permanent (Goldstein, 1971). Because of the many factors that affect drainage costs, estimates often show great variability.

Projects that are conducted by farm operators with their own equipment will typically have the lowest costs per hectare drained (Leitch and Scott, 1977; Heimlich and Langner, 1986). Subsurface drainage systems costs are a function of tile spacing and tile depth (Anthony, 1975). For surface projects, costs will be influenced by the length of drainage ditches and the amount of contouring required (Anthony, 1975; Manitoba Agriculture, 1985). With regards to wetland drainage projects, variations in cost may also arise from farm operators being at different stages of drainage operations (Danielson and Leitch, 1986). For example, assuming that wetlands are drained in order of increasing marginal cost, those that are just beginning to drain wetlands will be able to drain land at lower cost (Danielson and Leitch, 1986). Drainage cost estimates for different regions of Canada and the United States are summarized in Table 2.1. The variability in costs is evident as estimates for the same state/province can vary widely among studies conducted over similar periods.

2.2.5 Drainage Subsidies

In the past, the governments of Canada and the United States have funded large public drainage projects and provided direct subsidies to farm operators to encourage agricultural drainage. These actions were promoted in rural areas because wetlands were viewed as impediments to economic activity and agricultural productivity (Danielson and Leitch, 1986; Douglas, 1989). Subsidies often covered a portion of the costs and provided technical assistance for those contemplating drainage (Bardecki, 1987, 1989). Income tax write-offs of drainage expenditures were also allowed by governments (Nelson, 1986). Some have found that these subsidies significantly influence the number of drainage projects undertaken (Bardecki, 1987, 1989; Nelson, 1986). Most direct drainage subsidies are either no longer offered by governments or have been reduced.

Drainage, however, is also encouraged indirectly through other government programs. Any government program that improves the returns to or reduces the risk of farming could potentially encourage wetland drainage when returns to the farm operator would otherwise not warrant the expenditure (Bardecki, 1989). Programs such as price supports, export subsidies, import quotas and tariffs, and income stabilization and crop insurance programs may provide an incentive to bring wetland areas into production (Kramer and Shabman, 1993). Without government incentives, Nelson (1986) indicated the management of wetlands for agricultural and conservation purposes, such as grazing, livestock watering, haying and irrigation uses, might receive more attention.

Table 2.1 – Estimated drainage costs for various regions and drainage types.

Region	Author (Year)	Drainage Type	Cost/hectare
Alberta	Lyseng (2002)	Subsurface	$1,730-$1,977
Alberta	Myhre (1992)	Surface	$746-$914
Alberta	Rousseau (1983)	Surface	$104-$742
Alberta	Rousseau (1983)	Subsurface	$1,173-$2,995
Alberta	Wanchuk (1986)	Surface	$24-$1,200
Alberta	Wanchuk (1986)	Subsurface	$299-$3,393
North Carolina	Danielson (1986)	Surface	$1,804
North Carolina	Heimlich and Langner (1986)	Surface	$4,890
North Dakota	Heimlich and Langner (1986)	Surface	$463
North Dakota	McColloch and Wissman (1988)	Surface	$183
North Dakota	Leitch and Scott (1971)	Surface	$28-$46
Minnesota	Anthony (1975)	Subsurface	$741-$790
Minnesota	Danielson and Leitch (1986)	Surface	$255-$452
Minnesota	Danielson and Leitch (1986)	Subsurface	$988-$1,552
Minnesota	Goldstein (1971)	Surface	$40-$275
Minnesota	Goldstein (1971)	Subsurface	$305-$564
Minnesota	Leitch (1983)	Surface	$254-$453
Minnesota	Leitch (1983)	Subsurface	$988-$1,551
Mississippi Delta	Kramer and Shabman (1993)	Surface	$1,730
Saskatchewan	Saskatchewan Wetland Conservation Corporation (1993)	Surface	$150-$990
Saskatchewan	Saskatchewan Wetland Conservation Corporation (1993)	Subsurface	$1,360

Note: Costs included will vary; some will also include rehabilitation costs for the drained land in addition to the costs of the drainage system itself.

2.2.6 Drainage Regulations

Persons constructing drainage on their land may have to comply with regulations. Drainage regulations are developed at all levels of government. Regulations are intended to protect wetlands and downstream property owners that may be affected by drainage projects (Eidman, 1997). Permits are commonly used to regulate drainage (Heimlich et al., 1998; Lyseng, 2002).

2.2.7 Off-farm Drainage Impacts

The effects of drainage are not limited to the fields and areas in which the projects are constructed. Impacts of increased run-off from agricultural lands can cause property damage to downstream landowners and may negatively impact water quality (Lyseng, 2002; Myhre, 1992). The magnitude of these impacts will vary with the type of drainage system. Improving surface drainage moves more water into streams over a short period of time, increasing peak flows, stream-bank erosion and the amount of nutrients, pesticides, and soil in streams (Eidman, 1997). Similar effects are noted for subsurface drainage systems. While increases in peak flows may not be as large, more nutrients and pesticides may enter streams since water must move through the soil before entering subsurface tiles (Eidman, 1997). Drainage systems can be constructed with features that control the rate at which water leaves the property. Social costs will be reduced through the use of such features, but private drainage costs increase and the economic feasibility of drainage projects for farm operators is reduced (Huel, 2000; Myhre, 1992).

2.2.8 Economic Feasibility of Drainage Projects

Drainage is an investment decision; the farm operator forgoes current consumption in order to increase consumption in future periods (Copeland et al., 2005)[16]. Determining whether drainage is economically feasible requires an analysis of the benefits the farm operator expects to receive from drainage and the costs they will incur over time. Generally, if the benefits are greater than the costs, the project is feasible.

With respect to individual drainage projects, net returns to drainage are sensitive to crop rotation, yield, prices, input costs, and farm management skills (Leitch, 1983). Factors such as tax policies and agricultural programs may also impact returns (Leitch, 1983). For example, increased farm revenues through higher prices or increased government support, increased nuisance costs of farming around wetlands, and reduced costs of drainage caused by, for instance, technological advances would increase the number of economically feasible drainage projects and result in greater wetland loss (Danielson and Leitch, 1986). When publicly funded drainage projects are considered, success often depends on whether farm operators make investments in on-farm drainage systems (Found et al., 1976; Morris and Hess, 1986).

2.3 Review of Existing Literature

The literature review is broken down into three sections: analyses of drainage projects; wetland loss simulations; and studies that address the nuisance costs of wetlands. The majority of research in the first two sections has focused on analyzing the economic feasibility of drainage projects conducted by farm operators in a particular region. The studies in the first section generally used capital budgeting techniques to determine the economic feasibility of drainage for farm operators[17]. However, some studies also incorporated social costs into their analysis to address whether drainage was in the best interests of society. Simulation analyses conducted to address wetland drainage were particularly important since simulation analysis was chosen for the present study as well. The final section was included because few researchers have incorporated nuisance costs into their analysis.

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[16] Optimal investment decisions "maximize the expected satisfaction (expected utility) gained from consumption over the planning horizon of the decision maker (Copeland et al., 2005, p.17).

2.3.1 Analyses of Drainage Projects

In 1994, van Vuuren examined the likelihood of subsurface drainage occurring on imperfectly or poorly drained owned and rented land in southwestern Ontario. Through a comparison of the internal rates of return (IRR) for improving land from imperfectly or poorly drained to well drained through subsurface tile drainage, van Vuuren found that the IRR was at least twice as high for owned land in both scenarios and that under reasonable price scenarios the return for owner operators was sufficient to induce drainage. The study indicated that landlords were only able to capture benefits of drainage through increased rents, while landowners who operated their own land experienced increased yields and/or the ability to switch to higher valued crops. A hedonic analysis was conducted to capture the effects of increased drainage on rents. Average yields of corn on well drained soil versus imperfectly drained soil were used to indicate the effect of drainage on imperfectly drained soils, while switching from mixed grains to corn was used to show the impact of drainage on poorly drained soils.

Evidence that renting land does not provide the necessary returns to warrant drainage was also provided by van Vuuren and Ysselstein (1986) and Ketchabaw (1991). Both studies found that land operated by the owner had more drainage than rented land. Rented lands were not improved by tenants because of the insecurity of tenure, which was also noted by Morris and Hess (1986).

Cecile et al. (1985) provided an analysis of the Eastern Ontario Subsidiary Agreement Municipal Outlet Drainage Program. The goal of the program was to increase the returns to agriculture to levels similar to those in southwestern Ontario. This was a five year program beginning in 1979 that provided support for municipal outlet drainage. Under the program, $11 million was spent on 252 municipal drains. The subsidy covered two-thirds of the costs and the remainder was the responsibility of the farm operators. The study analyzed 64 drains in 14 counties in eastern Ontario. In the study, the authors found there was a lack of effective targeting of appropriate lands for drainage. Through benefit-cost analysis they also determined that few drains were likely to generate future benefits equal to the costs, even given a reasonably generous evaluation of benefits and conservative cost estimates. At discount rates of 10%, 7% and 3%, only 3, 6 and 16 of the 64 drains, respectively, were found to be cost effective. Assumptions used were: only soils limited by wetness that have potential for achieving net benefits were included, only engineering and tiling costs were part of the analysis, and a drain life of 20 years was assumed. Important factors not included were drain maintenance and environmental costs.

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[17] Capital budgeting is discussed in section 4.1.

A study by van Vuuren and Roy (1993) analyzed wetland use decisions on the east shore of Lake St. Clair in Ontario. The study compared returns from conversion of wetlands to agriculture against preservation using net present value (NPV) analysis. All additional crop benefits were evaluated for the conversion to agriculture scenario, whereas only the benefits of hunting, angling and trapping were used as the benefits of preservation. Therefore, the analysis only provided a lower bound on the benefits of preservation. Social net benefits of preservation and conversion were calculated to determine the most appropriate use of wetlands. Private net benefits were also calculated as a comparison. Many of the benefits and costs were similar for calculating social and private net benefits.

The main difference between private and social net benefits in this study were the taxes paid by landowners, the subsidies that private individuals received (not included in the social net benefit calculations because they are transfers from one group to another), and the benefits for which farm operators cannot appropriate rents because they accrue to those outside the boundary of the property. Their determination of social and private net benefits for agricultural conversion and wetland conservation showed that preservation would provide the greatest net benefits for society, while conversion was the optimal decision for the farm operator. The authors concluded that while the economy gains most from preservation there are strong incentives for farm operators to convert land to agriculture.

Several types of drainage projects in Minnesota were analyzed by Leitch (1983). The study estimated the returns to and costs of these systems. It examined the economic feasibility of drainage using NPV analysis and assessed the implications of nuisance costs as well. West-central Minnesota farm operators conducted random wetland drainage while south-central farm operators installed general field drainage systems that also resulted in wetland loss. Data were obtained through personal surveys of farm operators that had recently completed drainage projects. The analysis used a planning horizon of 15 years, discount rates of 8% and 12%, and excluded the cost of machinery since it assumed that the marginal additions to crop land would not change the machinery complement. Different scenarios also analyzed the impact of taxation as well. Reductions in nuisance costs of wetlands were not part of the benefits calculation. Therefore, using only increased crop revenues provided a lower bound of the benefits from wetland drainage. Drainage costs per hectare were by far the least expensive for farm operators that conducted surface wetland drainage and most expensive for those using random tiling systems for wetland drainage. Complete field drainage systems were somewhat cheaper than the random tiling systems. Leitch also mentions that although the costs of surface drainage systems were low, they were highly variable.

Leitch (1983) found that all forms of drainage were profitable using the higher discount rate of 12%. Only 1 of 15 farm operators experienced negative returns for surface drainage. Due to the low cost relative to crop returns, surface systems also provided payback periods of less than five years. The vast majority (47) of the 58 general field drainage projects had positive returns as well.

On the other hand, 9 of 19 farm operators that conducted random subsurface wetland drainage appeared to experience negative returns. The study also notes that nearly half of these farm operators received net dollar benefits lower than the average preservation incentive offered by the United States Fish and Wildlife Service. This suggested that other factors such as nuisance costs may have had a significant impact on drainage decisions. Also, the fact that some drainage projects resulted in net losses implied that farm operators have a willingness to pay to be rid of wetlands. Therefore, incentives for wetland preservation may need to compensate for these additional benefits.

Goldstein (1971) conducted some of the earliest research on the feasibility of drainage. The study analyzed the drainage of temporary and permanent wetlands in Minnesota to determine how agricultural subsidies (low interest loans, drainage subsidies and price supports) influenced drainage decisions and whether reclamation of wetlands would still occur without them. Although Goldstein (1971) recognized reduced nuisance costs as a benefit of drainage, these were not included in the model due to a paucity of information about them. Therefore, only increases in acreage, yield and input costs were used in calculating incremental returns to drainage. To estimate drainage costs, a small sample (27) of temporary wetland drainage projects in Minnesota were used. These costs ranged from $40-275/ha for surface projects to $305-564/ha for subsurface projects. Permanent wetland drainage costs were assumed to be 33% more than temporary drainage costs. Discount rates used reflected the borrowing rates at the time. The study also included some attempts at valuing wetlands in their natural state. However, these social values of wetlands only comprised values pertaining to waterfowl. Valuation efforts included an early application of the travel cost model that proved unsuccessful. Therefore, wetland values could not be explicitly included in the analysis.

Findings from Goldstein (1971) indicated that if the farm operator attempted to farm the temporary wetlands each year (i.e. the farm operator incurs the same machinery expenses on the field regardless of whether the temporary wetland has been drained) all subsurface and surface drainage projects were economically feasible, even without price subsidies. Utilizing the assumption that farm operators would incur additional machinery expenses through farming drained areas, none of the projects were economically feasible without price supports and drainage subsidies. However, price subsidies alone were enough to make all projects feasible. Goldstein (1971) mentioned that other agricultural subsidies may influence drainage projects at the margin. With regards to permanent wetlands, findings revealed that drainage was not feasible at free market prices and few projects were feasible when all agricultural subsidies were included.

Elliot and Mulamoottil (1992) compared wetland and agricultural net operating profits on Walpole Island in southern Ontario. This island is a First Nations Reservation with extensive wetland areas. Agriculture had been recently introduced to the island economy. The authors used a combination of personal interviews and existing data to establish operating profits for 1 ha of land in agricultural production and 1 ha of land in recreational and subsistence uses. Recreational activities that occurred within the wetlands areas were hunting, fishing and trapping. Revenues for the residents of the island from these activities included: fishing permits, guiding, duck hunting leases, pelt sales, duck plucking and income-in-kind revenues from the residents' own consumption. The agricultural enterprise on the island was also managed by the residents and corn and soybeans were grown on drained wetlands. Net operating profits for the hunting, fishing and trapping activities were $168.52/ha compared to $135.92/ha for agriculture. However, 75% of the crop area was assumed to grow corn and 25% was assumed to be planted to soybeans. Soybean net operating profits were somewhat higher than the operating profits for corn and a slight change in the percentage of land allocated to soybeans could show agriculture as having higher net profits. Nevertheless, hunting, fishing and trapping returns were shown to be comparable to agricultural returns. Hunting, fishing and trapping also required much less capital investment than agriculture, which exposed the residents to less risk. The island was also facing pressure on its recreational resources from increased usage by hunters and fishermen. The authors concluded that the results from the study should encourage more preservation to reduce the pressures on existing natural wetland areas.

Existing drainage systems within tiled drainage districts in north-central Iowa were analyzed by Kanwar et al. (1983). The authors assessed the state of drainage in the study area and determined whether drainage improvements were feasible using NPV analysis. Most of the drainage systems in the area were installed at the beginning of the 20th century and did not meet the needs of the farm operators in the area, since the capacity of the outlet drains was too low. On the other hand, the majority of fields had adequate drainage capacity and the benefits that farm operators could achieve from drainage were being constrained by the outlet drain capacity. The benefits and costs of improving the district drains and on-farm drainage were analyzed to determine whether improvements were appropriate. The authors found that only 68% of potential yields were being realized. Using discount rates of 12% and 16% and a planning horizon of 20 years, the authors found positive benefit-cost ratios for very poorly drained and poorly drained soil classes, and determined that somewhat poorly drained soils were not economical to drain. The authors also observed that tax deductions for drainage would raise benefit-cost ratios and farm operators may consider non-monetary benefits when making their drainage decisions.

Surface and tile drainage of wetlands in west central Minnesota was analyzed by Danielson and Leitch (1986) using a survey of farm operators who had recently drained land. Costs to drain wetlands in the area using surface ditches were highly variable, but generally fell in the range of $255/ha-452/ha in 1980 dollars. Maintenance of ditches was assumed to be equal to 3% of the initial construction costs per year for the expected life of the project (i.e. 25 years). Random tile drainage costs were between $988/ha and $1,552/ha. The returns to drainage were assumed to be increased agricultural production, decreased nuisance costs and a component for the net influence of intangibles. The authors used 8% and 12% discount rates and also added the impact of a 40% marginal income tax rate when ditch costs were deducted from taxable income. The NPVs of returns to ditch drainage, using increased agricultural production as the only benefit to drainage, were always positive and ranged from $222/ha-$635/ha depending on the assumptions used. Returns to tile drainage projects were lower than ditch drainage, but were generally positive (Leitch and Kerestes, 1981). These NPVs represented the minimum value of a one-time incentive payment that could be made to farm operators to encourage wetland preservation. A factor not reflected in the net present value calculation discussed by the authors that also makes drainage attractive was the fact that the average cost of acquiring 1 ha of new land through ditch drainage was $452 compared to over $1,730 in the market.

A summary of a survey of attitudes towards drainage was also presented in the Danielson and Leitch (1986) paper. Survey respondents included farm operators that did/did not sell land to the United States Fish and Wildlife Service, those who accepted/declined offers for wetland easements from the Fish and Wildlife Service and other farm operators. The survey found that 72% of the respondents felt they should be compensated for wetland preservation and 84% felt that a wetland tax credit would influence their drainage decision. Survey respondents would sell their land for 80% and accept wetland easements for 37% of the market value for cropland, respectively. Compensation offered by the Fish and Wildlife Service was actually higher than these responses. Participation in these programs, however, was low even though it appears that incentives were high enough.

Found et al. (1975) investigated drainage projects completed between 1965 and 1970 in Ontario to determine their economic and environmental impacts. Benefit-cost ratios were calculated to determine their economic impact. The types of projects studied were outlet drains funded through government grants. Seven townships were selected representing the full range of drainage scenarios in Ontario. Thirty-seven projects and 232 properties were studied in total. The study focused on local impacts since time constraints did not allow for investigation of regional and provincial impacts. The authors included increases in agricultural production as the benefits of drainage projects and both private costs and government funding as the total costs of the outlets. They analyzed each project at discount rates of 6%, 8% and 10% and drain lifetimes of 5, 12 and 20 years.

The different drain lifetimes accounted for the range of lifetimes in the different soil types. The research showed that most projects generated benefits for agriculture at the local level without causing severe environmental damage. There was considerable variation in benefit-cost ratios, but those in southern Ontario were consistently higher than in other areas of the province. The authors concluded that those projects that had poor benefit-cost ratios should not have been constructed in the first place since all of the factors that affect them should have been evaluated before a project was undertaken. The environmental impacts of the projects were deemed to be low. However, this is likely because the majority of the projects undertaken during this period were reconstructions or improvements rather than new projects. Previous research has shown that the most severe environmental impacts are wetland loss and channelization of streams (U.S. Council on Environmental Quality, 1973). The authors also recognized that the cumulative effects of drainage may be serious, such as increased flood peaks and effects on water quality. However, they did not show up at the local level.

Wanchuk (1986) studied surface and subsurface drainage projects in east-central Alberta. Purposes of the study were to assess the viability of drainage projects and examine the difference between perceived benefits and those actually received. The study used NPV and IRR calculations to assess the viability of drainage projects. Drainage projects were conducted by farm operators to remove temporary and permanent wetlands from their land. Some were causing salinity problems on their land in addition to being an obstruction within the field. Benefits and costs of drainage included were: revenues from an increased land base, estimates of labour used in the project, a component for time saved from the project, and crop damage caused by waterfowl. For certain farm operators, the cost of going around the wetland and wasted inputs were equal to the cost of inputs necessary to produce crops in the drained wetland area. The study was conducted using a survey and in-person interviews of farm operators that had conducted drainage projects in the past. Fifteen pairs of similar farms were studied. One of the farms in each pair conducted a surface drainage project and the other had conducted a subsurface project.

Using a 5% discount rate, only one of fifteen surface projects had a negative net present value while four of the subsurface projects generated negative returns when including all benefits and costs of drainage as well as taxes. Sensitivity analysis showed that subsurface projects were sensitive to reductions in the benefit stream as 11 of the 15 farms exhibited negative returns when benefits were reduced to 75% of increased crop revenues while only one other surface project generated negative returns under the same assumptions. From these figures, Wanchuk concluded that surface drainage can be viable under normal conditions. Of the 30 farm operators, 14 of 15 surface drainers mentioned that they would drain land again and 13 of 15 subsurface drainers would conduct another drainage project.

Other relevant findings from Wanchuk (1986) included farm operators' willingness-to-accept (WTA) compensation not to drain wetlands, their reasons for draining, cost estimates of drainage systems, advancements in seeding dates, and reductions in nuisance costs[18]. Responses for the WTA question ranged from $0 for those that did not feel they gained anything from draining to the market value of the land. Reasons for draining among farm operators were increased returns from a larger cultivated land base, removal of a nuisance factor, reduced waste of inputs, and being able to use larger machinery. Costs for surface projects ranged from $24/ha to $1,200/ha and averaged $401/ha. Subsurface drainage costs ranged from $299/ha to $3,393/ha and averaged $1,299/ha. These costs were solely for the system itself and included: surveying, system design, and construction costs. Additional costs involved in draining included clearing the land which averaged $144/ha for surface projects and $189/ha for subsurface drainage. Maintenance costs were also summarized and averaged $3.68/ha for surface projects and $2.47/ha for subsurface projects. Maintenance costs represent slightly less than 1% of the costs of the drainage system for surface projects and less than 0.25% for subsurface projects. Advancements in seeding dates were noted by most of the 30 drainers as well with advancements of, on average, almost 6 days being realized. Savings in machinery expenses averaged $157/year/farm with a range of $0-$972 for surface projects and $277/year/farm with a range of $0-$1,408 for subsurface projects. Input cost savings resulting from fewer wetland obstacles averaged $130/year/farm with a range of $0-$865 for surface projects and $347/year/farm with a range of $0-1,650 for subsurface projects.

Publicly funded drainage systems were the subject of a report prepared by Pearson and Kulshreshtha (2002). They analyzed ten projects that received planning, technical and financial assistance from the Saskatchewan provincial government. These projects were developed for the following purposes: agricultural drainage and flood control, flood damage reduction, backflood irrigation, and lake stabilization and habitat enhancement. The projects generally included the construction of ~~engineered~~ canals to facilitate the removal of spring run-off and excess precipitation. All projects conducted had agricultural benefits, while only some served the aforementioned other purposes as well. Agricultural benefits included lower incidence of crop losses because of flooding, earlier seeding dates resulting in better yields, production of higher valued crops in frequently flooded areas and increased cropland. There was mention of environmental impacts caused by such projects; however, little data were collected in this regard and these impacts were excluded from their economic analysis.

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[18] Willingness-to-accept is defined as the amount of income or other goods a person would require in order to give up a good (Cooper, 1995).

Generally, negative impacts were noted on wildlife habitat and there were no observable impacts on water quality with the exception of one project that had a lake stabilization and habitat enhancement component. In their analysis, the authors found that all projects generated positive NPVs at a 5% discount rate and 10-year average prices. The internal rates of return ranged from 7-33% and averaged 17%. These values were based on benefits accruing to farm operators in the form of increased crop production along with reduced damage to homes, roads and other public works caused by excess moisture. Including environmental impacts, in most cases, reduced the attractiveness of these drainage projects.

One of the most in-depth drainage studies was conducted by Rigaux and Singh (1977). Their three volume work was a benefit-cost evaluation of improving agricultural drainage systems in Manitoba based on the relationships between excess moisture and agricultural productivity, drainage improvements and the reduction in excess moisture, and drainage improvements and crop losses averted. Wetland drainage per se was not specifically addressed. In the first volume, a model to quantify precipitation excess, excluding spring runoff was developed. The model determined excess moisture using precipitation data, the size of the watershed, vegetation, slope, soil texture, land use, existing drainage capacity and soil moisture levels previous to precipitation events. The model specification allowed the authors to determine how changes in existing drainage systems would impact flooding and crop damage studied in the subsequent two volumes. Anecdotal evidence from farm operators suggested that severe crop damage occurs when water persisted in fields for longer than two days.

Volume two of Rigaux and Singh (1977) used the precipitation excess model and regression analysis to determine how crop yields of wheat, barley, flax and oats respond to flooding at various stages of crop development. Benefits of drainage improvements could then be determined by the frequency and extent of damages caused by excess moisture. Separate regression equations were calculated for each crop by soil type and for stubble and fallow crops. Soil types analyzed were clay, heavy loam, light loam and light sandy soils. Explanatory variables used in the regression were nitrogen and phosphorous application levels, soil class, and a precipitation index by month for May, June, July and August. The regressions were based on historical data from the Manitoba Crop Insurance Corporation and weather stations. Precipitation excess was calculated using weather station data and the precipitation excess model developed in volume one. Most of the equations, except for those estimated for clay soils, did not indicate strong negative impacts of precipitation excess on crops. Precipitation excess in May was most often found to have a positive effect on yield while July was found to have the largest negative effect. The authors determined that the positive effect in May helps protect crops against dry periods later in the growing season, whereas the negative effect in July was the result of crops not being able to recover at later stages of growth. Results also indicated that barley and wheat had the highest losses caused by excess precipitation as a percentage of average crop yield, followed by oats and flax, respectively. Rigaux and Singh concluded that watersheds with mostly clay soils and a high percentage of cropland seeded to wheat and barley would receive the greatest benefits from improved drainage.

The third volume related increases in the capacity of the drainage systems to crop damages avoided. Rigaux and Singh (1977) indicated that in addition to constructing public systems, farm operators must make capital investments in on-farm drainage to realize benefits. Benefit-cost ratios were calculated for all 15 study areas and crop losses averted were the only benefits assigned monetary values. Costs included investment in public infrastructure as well as necessary on-farm structures needed to realize benefits. The project life was assumed to be 15 years. However, annual maintenance costs of 7% of the initial capital costs were assumed so benefits did not deteriorate over the project life. Benefit-cost ratios were calculated for the existing drainage system and three possible larger systems. The largest system analyzed had a capacity that would only be exceeded, on average, 3 times over a 100-year period. Using a discount rate of 10%, it was determined that only six of the fifteen projects warranted increased investment in drainage. Study areas that had clay soils, flat topography, and a high proportion of land dedicated to crop production generally resulted in economically feasible projects. Flat topography resulted in lower cost systems while the other two factors generated larger benefits. Sensitivity analysis showed the results were insensitive to increases in the project life, but quite sensitive to changes in cost assumptions.

Myhre (1992) studied the economic feasibility of uncontrolled and controlled drainage projects on a farm near Edmonton. The controlled drainage project was a backflood drainage system which retained water in order to allow additional moisture to soak into the land, the purpose of which was to increase yields. This type of system also reduced peak flows during spring runoff and mitigated downstream affects. The drainage project studied began as an uncontrolled system where a backflood system was installed one year after the uncontrolled system was completed. The wetland on the site was a 23.25 ha non-permanent wetland that provided no agricultural benefits to the farm operator. Forage crops were subsequently produced on the drained land. Drainage costs were $746/ha and $914/ha for the uncontrolled and backflood systems, respectively. Operating and maintenance costs were 2% of initial capital costs. The on-farm analysis concluded that both the uncontrolled and controlled systems were economically feasible using a 5% discount rate and a 30-year project life. When off-site costs were included, waterfowl hunting days lost and the cost of public drainage works needed to prevent downstream flooding, only the backflood system remained economically feasible. A social discount rate of 3% was used for analyzing the total (private and social) cost of the system. However, the backflood system would still be economically feasible at a discount rate of 5%. The uncontrolled system was not economically feasible when off-site costs were included because peak flows during spring flooding were greater and a more expensive off-site system was needed to prevent downstream flooding.

2.3.2 Wetland Loss Simulations

A national wetland simulation model was constructed by Heimlich et al. (1998) within their comprehensive publication on wetlands and agriculture. They analyzed wetland hydrology and agricultural productivity for several areas to make estimates of wetland loss in the absence of the "Swampbuster" provision over the 2002 to 2012 period. This study was conducted because it was believed that future United States farm bills would include reduced levels of support for the industry, rendering the "Swampbuster" provision inconsequential. Two scenarios of wetland conversion, high and low, were established using expected profits from conversion. Nuisance costs were not included because they were deemed too difficult to estimate within their model. After the high and low conversion rates were estimated, the economic effects of increased cropland on crop production, commodity prices and farm income over the long run were simulated. It was estimated that 5.34 and 2.35 million ha of wetland would be profitable to convert in the high and low conversion scenarios, respectively. Using feedback effects on prices, wetland conversion was expected to lead to an increase in cropland area of 2.02 and 0.82 million ha and reduce aggregate net farm income by more than $3.2 billion (4.9%) and $1.6 billion (2.5%) over the long run for the high and low conversion scenarios, respectively. Regionally, there were a few areas predicted to have increases in farm income. These regions had large amounts of wetlands that were feasible to convert and relatively small existing cropland bases. The main corn producing region in the United States, the Midwest, was estimated to experience over 50% of the reduction in farm income in both scenarios because few wetlands remained that could be converted to offset the reductions in price. Due to the negative implications increased cropped area had on prices and net farm income, the authors concluded that wetland conservation was in the best interests of the farm sector.

Changes in economic returns to wetland drainage arising from different economic and policy environments in the 1980's were simulated by Kramer and Shabman (1993). Two policy reforms were enacted to reduce incentives to convert wetlands; the "Swampbuster" provision of the Food Security Act of 1985 and the elimination of income tax deductions for drainage expenses enacted in the Tax Reform Act of 1986. The area studied was the bottomland hardwood forest of the Mississippi Delta region. Three representative farms within areas of varying cropping practices, one in each of Mississippi, Louisiana and Arkansas, were developed for analysis. Conversion of wetlands to agricultural production involved clearing of trees and vegetation and the installation of surface drainage ditches to move water into river channels at a cost of about $1,730/ha. Monte Carlo simulation was used allowing commodity prices and yields to be stochastic. Ten years of detrended historical data were used to develop the distributions for these variables. Correlations between variables were accounted for in the analysis.

Kramer and Shabman (1993) calculated the net present value and variance of returns for farms under five different scenarios: the 1985 economic and policy environment, the 1987 economic environment with no policy reforms, the 1987 economic environment with only the "Swampbuster" policy reform, the 1987 economic environment with only the tax policy reform; and the 1987 economic environment with both policy reforms. These scenarios allowed the authors to determine the impact of each policy reform as well as how the changing economic environment affected returns to drainage. Drainage was not economically feasible in Louisiana even before the policy reforms in 1985 and even less so in 1987, and only marginally feasible in Mississippi. However, drainage returns were positive in Arkansas.

Both the "Swampbuster" and tax policy reforms had large negative impacts on the net present value of returns. The "Swampbuster" provision also increased risk for farms since a farm operator would lose the protection of government programs if wetlands were drained. The tax policy reform, however, decreased the risk associated with wetland conversion by reducing the variance of returns. Kramer and Shabman (1993) indicated that conversion of wetlands to agriculture may not have been feasible even before the policy reform and hypothesized that this could be because the marginal costs of drainage may be rising. They also feel that drainage pressures in this region would continue to be low due to the agricultural economic environment and that even if price support programs were significantly reduced in future farm bills, making the "Swampbuster" provision less effective, the tax policy reforms would still provide considerable protection for wetlands.

Danielson (1989) conducted a simulation analysis for the Pocosin Region of Washington County, North Carolina to show the effect of farm policies on farm returns. The policies analyzed in this study were price and income support programs, as well as income tax deductions for land clearing and wetland drainage that are either classed as land-clearing activities or soil and water conservation expenditures. The latter are eligible for greater tax concessions. A representative farm of 312 ha with a 130 ha tract to be drained was used for the analysis. Commodity prices and yields were stochastic and were randomly generated from the period 1975-1984. The policies analyzed and production costs were based on 1985. Drainage costs were assumed to be $1,804/ha and $20/ha/year was used as an estimate of maintenance costs. Results showed that removing price and income supports and tax breaks would reduce the annualized net present value of the investment from $158/ha to $130/ha. In this analysis, removal of tax provisions resulted in greater reductions in NPV than did price and income supports. The NPV in this analysis, however, only measured the amount available to pay costs of land, labor, management, overhead and risk. Therefore, Danielson (1989) concluded that previously drained wetlands provided sufficient returns, but the feasibility of new drainage projects would be questionable.

The Prairie Pothole Region of the United States, which covers parts of Montana, North and South Dakota, Minnesota, and Iowa, was the area of interest for a simulation analysis performed by McColloch and Wissman (1988). Six representative farms were used in the analysis since very different farm enterprises existed across the region. Corn and soybeans were grown in Minnesota, Iowa and eastern North and South Dakota, whereas lower valued crops such as wheat, barley and oats were more prevalent in western North and South Dakota and Montana. Drainage systems also differed across the region; subsurface tiling was common in the eastern and southern areas, whereas surface systems were generally used as one moved west and north. The simulation compared net present values and coefficients of variation of farms that conducted drainage and those that did not. During the simulation period, the only manner in which farms were able to expand crop acreage was through drainage. For simplicity all drainage was assumed to occur at the beginning of the analysis. The period simulated was 1975-1984 using 50 iterations and stochastic commodity prices and crop yields. The simulation analyzed how different agricultural programs affected the NPVs and coefficients of variation for each farm. Programs included in the analysis were: United States Fish and Wildlife Service easements; Water Bank programs, direct drainage subsidies; price and income supports; disaster assistance/crop insurance; interest rate subsidies; and tax incentives on drainage expenses[19].

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[19] The Water Bank program was the first program created to protect wetlands in the United States (Heimlich et al., 1998). It provided annual incentive payments to landowners who agreed to preserve their wetland resources (Heimlich et al., 1998).

Results of the McColloch and Wissman (1988) analysis showed that drainage always resulted in improvements in NPV compared to undrained farms. Removal of price and income supports had the largest impact on NPVs. However, the authors were reluctant to conclude that price and income supports induced drainage since it was feasible even in their absence. They did qualify this statement by mentioning that support programs may have provided incentives to drain for farms that were only marginally profitable and for future drainage projects in which the marginal cost of drainage would be higher. Other agricultural programs studied in the analysis did not appear to have significant effects on NPVs or incentives to drain either. A possible explanation why agricultural support programs and drainage incentives did not appear to induce drainage was that drainage costs in this region were generally low and therefore typically provided significant returns.

The analysis of conservation programs in the McColloch and Wissman (1988) study indicated that United States Fish and Wildlife Service easements and the Water Bank program did not provide sufficient support to offset foregone revenues from drainage even though they were designed to do so. Here again, the authors urge caution when interpreting these results since the flexibility of the programs to offer different levels of payments to farm operators could not be modeled. Also, since participation in these programs was high, farm operators must have felt sufficiently compensated. Farm operators may have accepted lower payments than estimated because they were interested in conservation.

Heimlich and Langner (1986) conducted simulation analyses for hypothetical farms in both the Pocosin Region of North Carolina and the Prairie Pothole Region of North Dakota. The purpose was to determine the effect of different drainage policies, specifically the "Swampbuster" provision and tax subsidies, on returns to farming. A ten year planning period was used, and the drained land was assumed to be sold at the end of the period in both cases. In North Carolina, complete blocks of land were drained for crop production in either half or full-section blocks. The analysis used a half-section reclamation project. Such projects required the use of deep ditches, canals and pumping stations in order to remove excess water. These projects cost approximately $4,890/ha of drained land. The results show that tax subsidies decreased taxes owed by 36% and that loss of support payments reduced after-tax income by 26%. The authors concluded that the loss of support payments provided significant protection for wetlands, even without considering the increased risk that an enterprise would incur without these programs. However, they also note that participation in farm programs was low in this region and that large corporate farms were typically those conducting drainage projects. Obtaining tax benefits provided by drainage was likely motivating these firms to convert land.

The analysis of North Dakota drainage projects by Heimlich and Langner (1986) was conducted for a 474 ha farm primarily engaged in wheat production. The North Dakota farm was assumed to drain a 4.05 ha pothole at a cost of $463/ha. Denial of farm program payments through the "Swampbuster" provision would result in negative returns for the farm enterprise, decreasing after-tax income by 145%. Taxes owed in this scenario actually rose 6%. In North Dakota, the "Swampbuster" provision was a greater deterrent to wetland drainage because wetland area was a relatively small percentage of total cropped area and participation in farm programs was much higher than in North Carolina. Since conversion costs were quite low, benefits provided by tax breaks were low.

A simulation model with dynamic optimization was used by Stavins (1989) in a study of the optimal use of forested wetlands in Mississippi. The study area had only 20% of its original wetland area, mostly because Federal flood control and drainage projects created incentives that favored conversion (Stavins and Jaffe, 1988). The objectives of the research were to determine how the rate of wetland conversion over the period of 1935-1984 compared to what would have been socially optimal and what future wetland conversion could be expected through until the year 2000. The analysis compared scenarios with and without Federal projects. Assuming that farm operators attempted to maximize the expected economic returns from the set of activities that may be carried out on their land, that farm operators were risk neutral and that wetland values were in the range of $62 to $2,471/ha, Stavins found that no net wetland loss would have been optimal with Federal projects if the environmental benefits were $370/ha/year and $198/ha/year without those projects. The difference between the two figures ($172/ha) represented the average annual payment that farm operators would accept to forgo the Federal projects. The model predicted that 465,000 more hectares were converted with the Federal projects. Stavins (1989) was also able to calculate an average annual value of $136 that would have stopped a typical hectare from being drained. Beyond 1984, the author predicted further wetland drainage and that the 1984 ratio of forested wetlands to cropland would be maintained if the environmental value of wetlands was at least $432/ha/year.

2.3.3 Studies on Nuisance Costs of Wetlands

A study by Accutrak Systems (1991) estimated the additional costs incurred by farm operators through maneuvering around wetlands. Southern Saskatchewan and Manitoba served as research sites. The monetary value of driving around 17 different wetlands was calculated by comparing actual distance traveled to the ideal distance without any obstacles. Additional distances traveled were calculated by mapping a farm operator's path in a field using navigational equipment and analyzing this data with computer programs specifically written for the study. A typical wetland of 0.06 ha was found to increase the driving distance in a field by 0.444 km and would cost on average $24/year to maneuver around, assuming a two year crop/summerfallow rotation and 10% overlap of inputs. The researchers noted that large variations in driving habits of farm operators resulted in large differences in extra distances traveled caused by wetlands of similar size. They also found that larger wetlands were only incrementally more costly to farm around.

Desjardins (1983) examined the costs of farming around obstacles using a linear travel pattern on a typical quarter section of land. The costs were estimated by calculating the difference between the distances traveled in a quarter section with and without obstacles and assigning the appropriate costs for machinery operation and labour. Obstacles analyzed included wetlands, irrigation ditches, roads and well sites. Manual calculations were performed to estimate distances traveled in a quarter section, which were separated into turning distance, headland distance and linear travel distance. Different travel speeds for the different distances were used to calculate time spent in the quarter section. Per hour machinery operating and farm labour costs were then assigned to the travel times to establish economic costs. Wheat, barley, canola, alfalfa and sugar beet crops were included in the analysis to account for different operations performed in the production of different crops. Using a perfectly circular shaped 10 ha obstacle located either in the center or a corner of a quarter section, the author found increases in per hectare costs for wheat, barley, alfalfa and sugar beet crops in the range of 2.33-3.79% and 0.33-1.00% for an obstacle in the center and in the corner of the quarter section, respectively. Alfalfa typically had the lowest increased costs since few field operations were required after the establishment year. In the analysis specific to wetland obstacles, increases in the production costs of canola were 12% and 14% for a single 9.4 hectare slough and four smaller sloughs totaling 9.4 hectares in size, respectively. The analysis indicated that irregular shaped objects such as wetlands have a much larger impact on farm operations than the regular shaped obstacles analyzed.

Aldabagh and Beer (1975) used a slightly different approach to monetizing the impact of drainage on farm operations by estimating the benefits of timelier field operations achieved through improved drainage in Iowa. They found that, on average, a farm operator would have an additional 16 days during seeding by decreasing tile spacing from 98 to 24 meters in a general field drainage context. The improved drainage system removed excess spring moisture more rapidly, which increased the number of workdays during the critical planting season. Using an equation for calculating the economic penalty of untimely operations, the improved drainage system would result in monetary benefits of $27.67/ha/year, assuming the farm operator followed a corn/soybean rotation.

2.4 Chapter Summary

Several functions that are valuable to society are associated with wetlands. Benefits provided by wetlands are mostly in the form of public goods. The public good nature of wetland benefits has implications for preservation, as private landowners are unable to extract rents for providing these benefits. This is a reason why significant wetland drainage has been observed in North America and many other parts of the world. Conversion of wetlands to agricultural uses has been responsible for the majority of these losses and drainage has often been encouraged through subsidies. Economic theory suggests that compensating farm operators for the agricultural benefits that they would receive through wetland drainage would encourage wetland preservation. Continued research into wetland values has resulted in greater awareness of the benefits provided by these areas. Wetland loss, however, still continues. Further wetland loss could impair the ability of wetlands to provide benefits since wetlands are part of many ecological systems and interact with one another.

Draining wetland areas for agricultural uses is attractive to farm operators for several reasons. Not only does it allow a farm operator to expand their cultivated land base, but can also provide yield increases and shifts to higher valued crops. Draining of wetlands also removes nuisances that result in increased costs for farm operators. Different types of drainage systems exist and the type of drainage used by a farm operator will depend on several factors including the purpose of the drainage project, expected benefits, drainage costs, regulations, subsidies, existence of drainage outlets, and the characteristics of the land.

Extensive research has been conducted regarding drainage of wetlands for agricultural purposes. However, there have been few studies conducted in Western Canada and nearly no research carried out in Saskatchewan. Investigation of drainage research conducted in North America found that conclusions drawn from this research has produced mixed results. In some areas, drainage has proved to be economically feasible for farm operators, whereas expenditures on drainage have proven not to be in a farm operator's best interest in others. The same conclusions apply to research that investigated publicly funded drainage projects. For research analyzing both private and social costs and benefits of drainage, preservation was often found to be in society's best interest while conversion to agriculture was often in the farm operator's best interest.

The material presented in this chapter indicated that research focused on preventing wetlands from being converted to agricultural uses should analyze the returns that farm operators receive from drainage. Calculating these returns indicates whether drainage is economically feasible and provides estimates of compensation that farm operators may accept to forgo drainage. However, benefits and costs of drainage varied considerably among the literature reviewed. Thus, it is important to have relevant data for the specific study area pertaining to the benefits and costs of drainage. Surveys of farm operators that recently conducted drainage were often utilized to understand the benefits and costs of drainage in particular regions. Existing research also indicated that NPV analysis and simulation models are appropriate techniques for addressing wetland drainage issues. A limitation of many of the research studies reviewed was that they were only able to calculate a lower bound of the benefits a farm operator received through drainage. Nuisance costs of wetlands were often excluded from the analysis. The few studies that tried to estimate nuisance costs concluded that these costs may be significant and, therefore, an important factor in drainage decisions.

Chapter 3: The Study Area

A detailed description of agriculture, drainage, and wetlands in the study area are presented in this chapter. A broad overview of the region in which the study area lies and the importance of the wetlands in this area is provided along with a discussion on the types of drainage conducted, how drainage is carried out, and regulations and subsidies that pertain to farm operators contemplating drainage. Data are then presented regarding agriculture, drainage, and wetlands in the study area. Agricultural data provided insight into farm sizes, crops grown, livestock production and farming practices used in the area. Drainage and wetland data provide insight into the area and numbers of wetlands on agricultural land and the level of drainage activity in the area.

3.1 The Prairie Pothole Region

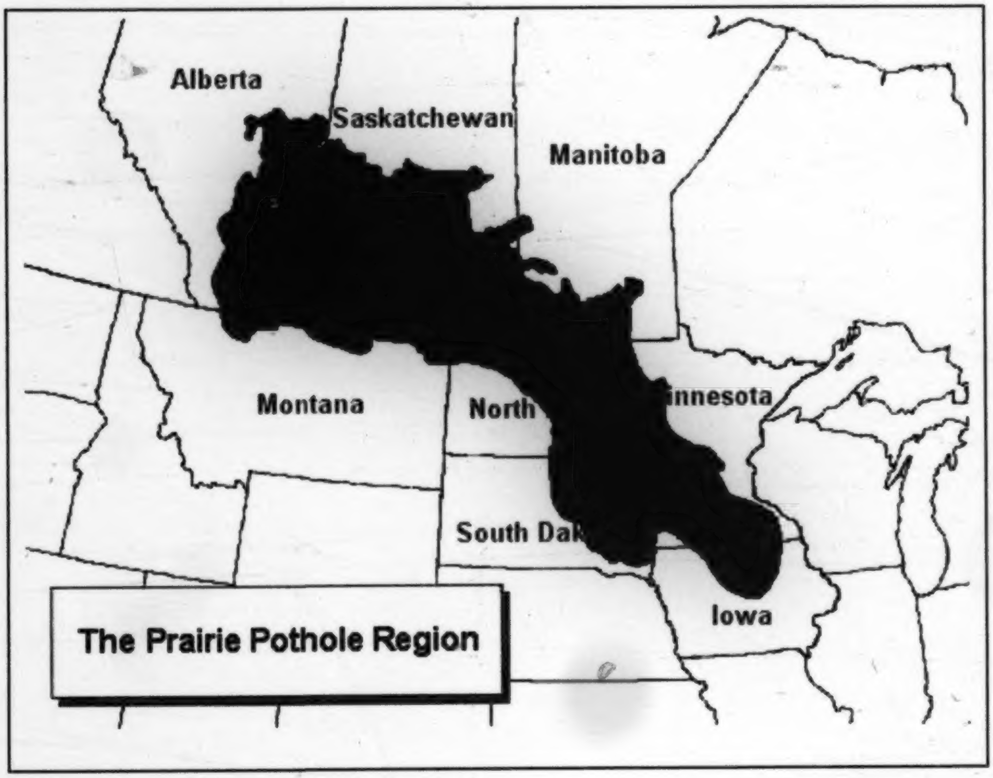
The Prairie Pothole Region, shown in Figure 3.1, includes parts of the provinces of Alberta, Saskatchewan and Manitoba in Canada as well as portions of Montana, Minnesota, North Dakota, South Dakota and Iowa in the United States. Potholes are wetlands that were formed when retreating glaciers from the last glaciation left large chunks of ice buried in the soil (Huel, 2000). When this ice melted, depressions were created that collected run-off (Huel, 2000). The Prairie Pothole Region covers an area of about 777,000 km^2 and about two-thirds of this area lies within Canada (Leitch, 1983). The area once contained approximately 25 million wetlands, a density that was unmatched anywhere else in North America (U.S. Fish and Wildlife Service, 2003). The most recent wetlands data for Saskatchewan estimated the province had about 1.5 million wetlands that cover about 1.7 million ha (Huel, 2000). Over 80%, were less than one hectare in size, while less than 0.25% were greater than 50 ha in size (Huel, 2000).

This relatively small region of North America is an important breeding ground for waterfowl and is estimated to account for approximately 50%-80% of total North American duck production (Batt et al., 1989; U.S. Fish and Wildlife Service, 2003). Drainage pressures in this region are deemed to be high (Nelson, 1986). Drainage projects in the Prairie Pothole Region utilize both surface and subsurface methods. However, in Canada, drainage is typically conducted through surface methods in the fall using a farm operator's own equipment, which can be very economical (Leitch, 1989). It is estimated that half of all prairie potholes were drained by 1950, mostly for agricultural purposes, and more continue to be drained (Leitch, 1983; 1989). Drainage in Saskatchewan has occurred at a rate that is lower than that of the entire Prairie Pothole Region. To date about 40% of the province's pre-settlement wetlands have been drained (Huel, 2000).

3.2 Drainage in Saskatchewan

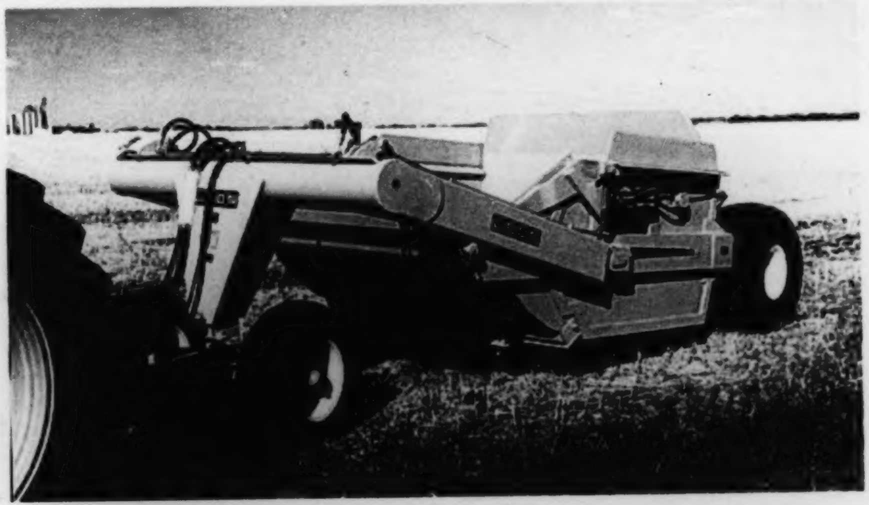
Drainage projects in Saskatchewan are mostly surface projects performed in the fall by the farm operator through the use of their own equipment. A scraper is the main implement used in these projects. A picture is provided in Figure 3.2. The scraper enables the farm operator to contour the land and create ditches to remove water from fields.

Figure 3.1 – The Prairie Pothole Region


Alberta
Saskatchewan
Manitoba
Montana
North
innesota
South Dak
Iowa
The Prairie Pothole Region

Source: United States Fish and Wildlife Service (2003)

Figure 3.2 – Picture of a typical scraper used in surface drainage projects conducted by Saskatchewan farm operators



Source: Leon's Manufacturing Company, Inc. (2005)

Some ditches are so subtle that it is difficult to tell that the landscape has been modified in any way, whereas others are deep enough that a farm operator must farm around them.

The construction and operation of drainage projects in Saskatchewan was initially regulated by the provincial government under The Drainage Control Act (Newcombe, 2004). The Drainage Control Act was replaced by The Water Corporation Act in 1984, which was then replaced by the Saskatchewan Watershed Authority Act in 2002 (Newcombe, 2004). The Saskatchewan Watershed Authority (SWA) is a Saskatchewan Crown corporation whose mandate includes management and protection of water, watersheds and related resources of the province, enhancement of water quality and availability of water, and coordination of conservation programs (Government of Saskatchewan, 2002). SWA receives and approves applications for drainage within the province. Under the Act, a person must obtain authorization before proceeding with wetland drainage that diverts water off their property (Government of Saskatchewan, 2002). The Act allows for civil action against those that do not obtain authority to drain wetlands which cause losses or damages to others. A landowner, however, is not responsible for water that naturally runs off land during precipitation events (Lyseng, 2002).

Funding for organized drainage projects in Saskatchewan has been available under the Rural Water Control Assistance Program for about 50 years (Newcombe, 2004). The level of funding offered under the program was reduced in the late 1980's from two-thirds to one-half of project costs (Newcombe, 2004). One of the purposes of the Rural Water Control Assistance Program is to alleviate flooding and drainage problems on agricultural land (Saskatchewan Watershed Authority, 2003a). Under the program, funding is available to groups of farm operators who may be organized as Conservation and Development Areas (Saskatchewan Watershed Authority, 2003a). For private drainage, funding for 50% of project planning costs up to $4,000 is available through SWA (Saskatchewan Watershed Authority, 2003b).

Conservation and Development Areas (CDA) have been organized since the Conservation and Development Act was passed in 1949 (Newcombe, 2004). A CDA is formed through a petition that must be signed by at least two-thirds of the landowners within the proposed area (Government of Saskatchewan, 2002). The Act allows for collection of funds from benefiting landowners within the area to cover the costs of constructing and maintaining drainage works. As of 2004, there were 106 CDAs with approximately 3,000 kilometers of drainage ditches that serve about 1.82 million ha of cultivated land (McFarlane, 2004). In 1967, The Saskatchewan Conservation and Development Association was formed in 1967 to represent the interests of each CDA within Saskatchewan (McFarlane, 2004).

3.3 The Rural Municipality of Emerald

The area studied was the rural municipality (RM) of Emerald (277) in Saskatchewan, Canada. This RM was chosen because it was identified as an area of importance by Ducks Unlimited Canada (DUC). Wetland drainage is conducted in this area, but significant area of wetlands remains that are at risk of drainage. It is in the southwest corner of crop district 5B, about halfway between Humboldt and Yorkton. There are no major centers and a CDA has not yet been established within the RM of Emerald.

Average land values in the RM of Emerald are approximately $640/ha[20]. Figure 3.3 is a map of the crop districts in Saskatchewan. Rural municipalities utilized in the study are highlighted on this map.

According to a 1994 soil survey of the region there are 86,866 ha of land within the RM (Saskatchewan Institute of Pedology, 1994) [21]. It lies entirely in the black soil zone[22]. Almost all of the soil is classified as loam. Seventy-one percent of the land base (61,958 ha) is in the top three Canadian Land Inventory (CLI) classifications of soil capability for agriculture, which are suitable for producing cash crops (Cecile et al., 1985) [23]. The CLI rating system uses soil and climatic characteristics alone to determine the potential capability of soils to produce field crops under the assumption that the land has been cleared and is under good soil management practices (Cecile et al., 1985). In Emerald, the 1994 soil survey revealed that salinity is not a problem for 98% of the RM; stone problems ranging from non-existent to slight represented 53% of the area; moderate stone problems where annual clearing is recommended accounted for 46% of the region; wind erosion potential was exclusively in the very low to low categories; very low to low water erosion potential existed for 72% of the RM; water erosion potential in the moderate range comprised 28% of the RM; ideal soil pH levels, in the range of 6.8-7.5, were found in 28% of the region; and slightly alkaline soil pH levels accounted for 72% of the RM. The ratings indicate the there are no severe limitations to agriculture in the area. However, few hectares (< 4%) were rated as suitable for irrigation. Wetlands and poorly drained soils comprised 20% of the total area. These areas represent possible drainage opportunities in the RM.

Census of Agriculture data for 1996 and 2001 provided by Biggs (2004) indicated that 76,715 ha of land were operated by farm operators in 2001 in the RM of Emerald or about 88% of the land indicated in the soil survey discussed previously[24]. As of 2001, there were 202 agricultural operations in this RM. The area of land seeded to field crops was 53,056 ha with an additional 10,932 ha in summerfallow. According to the 2001 Census of Agriculture, an average farm enterprise within this area was comprised of 379 ha of land, of which 75% was owned and 25% was rented from others or leased from governments. Of the 379 ha of land, 317 ha were cultivated to be used for crops. At 64.75 ha/quarter section, this was just under five quarter sections of cropland.

The major field crops grown in Emerald, in descending order of area grown were: spring wheat (16,191 ha), canola (11,255 ha), barley (7,769 ha), and oats (6,822 ha). These were the only crops that comprised at least 10% of the crop and summerfallow area from the 2001 Census of Agriculture. Although area seeded to spring wheat and barley declined since 1996, they still represented a considerable percentage of field crops grown. For the most part, canola and oats experienced gains in area seeded at the expense of spring wheat and barley. Peas and alfalfa, however, gained considerable area as well, but still only represented about 5% and 3% of total crop and summerfallow area, respectively. Peas have been gaining popularity throughout Saskatchewan as a rotational

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[20] This value was determined using land sales data from 2000 through early 2005 (Boychuk, 2005a). Sales figures were deflated to 2003 using CPI data and then the total area sold was divided by the total value of all sales.

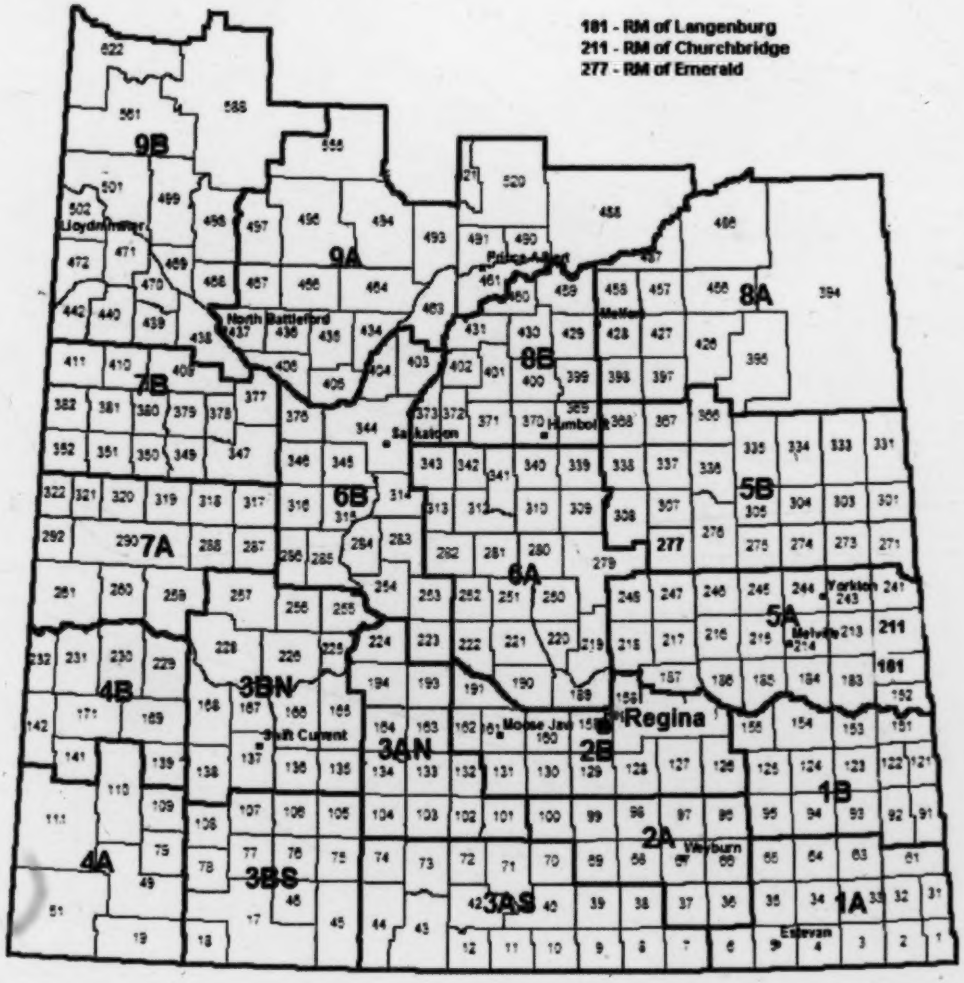
[21] Data for the 1994 Saskatchewan Soil Survey for RM 277 are summarized in Appendix B.

[22] A map of the Soil Zones of Saskatchewan is provided in Appendix C.

[23] Further explanations of Canadian Land Inventory classifications are given in Appendix D.

[24] Census of Agriculture data for RM 277 are summarized in Appendix E.

Figure 3.3 – Crop districts of Saskatchewan


181 - RM of Langenburg
211 - RM of Churchbridge
277 - RM of Emerald
9B
9A
8A
8B
7B
7A
6B
6A
5B
5A
4B
4A
3BN
3BS
3AN
3AS
2B
2A
1B
1A
Lloydminster
Prince Albert
North Battleford
Melfort
Saskatoon
Humboldt
Yorkton
Melville
Swift Current
Moose Jaw
Regina
Weyburn
Estevan

Source: Saskatchewan Agriculture Food and Rural Revitalization (2004a) tool. In Emerald, summerfallow still represented 17% of the total crop and summerfallow area, though it experienced a 24% decline from 1996.

Livestock production is relatively insignificant in this area. In 2001, the Census of Agriculture indicated that there were 4,846 cattle on agricultural operations, an average of less than 24 per operation. Cattle numbers in the region declined somewhat (8%) from 1996 Census of Agriculture totals. Other than cattle, there were large poultry operations in the RM, but no large hog operations. An analysis of the different Census of Agriculture farm types in Saskatchewan indicated that 162 farms were classified as cash crop farms and 28 were beef cattle farms[25]. An average of only 13 cattle were raised on each cash crop farm, while approximately 80 were raised on each cattle farm. Thus, it was not be necessary to include cattle on the model farm, since it appeared that few cash crop farms had significant cattle numbers. Further analysis of cash crop farms in the RM of Emerald indicated that 46% of them had annual sales of less than $50,000 in 2001, 27% had sales between $50,000 and $100,000, and 28% had sales greater than $100,000. The majority of the farms within the highest sales class had sales below $250,000.

Data specific to each quarter section in the RM of Emerald for the year 2004 were provided by DUC (Boychuk, 2005b). The RM is comprised of about 1,295 quarter sections. According to this data source, the total land within the RM is 83,155 ha, slightly less than the figure indicated in the 1994 soil survey. There were 2,027 intact wetlands (those that have not been cultivated for sowing crops in dry years) which comprise 11,715 ha. Histograms of wetland area and counts of wetlands are available in Figures 3.4 and 3.5, respectively. Figure 3.4 indicates that wetland area on a quarter section was quite variable. Numerous quarter sections (307) still had at least 10 ha of wetlands. On the other hand, Figure 3.5 reveals that all quarter sections had at least one wetland, almost two-thirds of the quarter sections in the RM of Emerald had only one wetland, and few (66) quarter sections had more than three wetlands. Mean values for wetland area and counts on a quarter section were 9.05 ha and 1.57, respectively. The quarter section with the most wetland area had 34.45 ha of wetlands, while 13 was the largest number of wetland areas within any particular quarter section. On the other hand, 0.03 ha was the lowest wetland area on any individual quarter section and one was the fewest number of wetlands on any particular quarter section. There were also approximately 23,100 wetlands that had either been drained by the 1,255 kilometers of existing drainage ditches in the RM, or cultivated for cropping in dry years[26]. Nearly all, 93%, of the quarter sections had drainage ditches.

To establish areas and counts for drained wetlands and cropped basins, another file was received from DUC where data transformations were performed to separate the two types of wet areas (Boychuk, 2005b). These estimates were used in a historical analysis of the study area. Those areas with drainage ditches emanating from them were identified as drained wetlands and those without were deemed to be cropped basins (Boychuk, 2005b). This data transformation resulted in 959 quarter sections with information pertaining to both previously drained areas and cultivated basins in addition to the previously received information. On these quarter sections there were 13,641 cropped

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[25] Census of Agriculture farm type is determined by the commodity that comprises 50% or more of revenues.

[26] Wetland areas that are cultivated for cropping in dry years are hereafter referred to as cropped basins. They are low-lying areas that may hold water during seasons characterized by high rainfall.

Figure 3.4 – Histogram of wetland area for quarter sections in the RM of Emerald

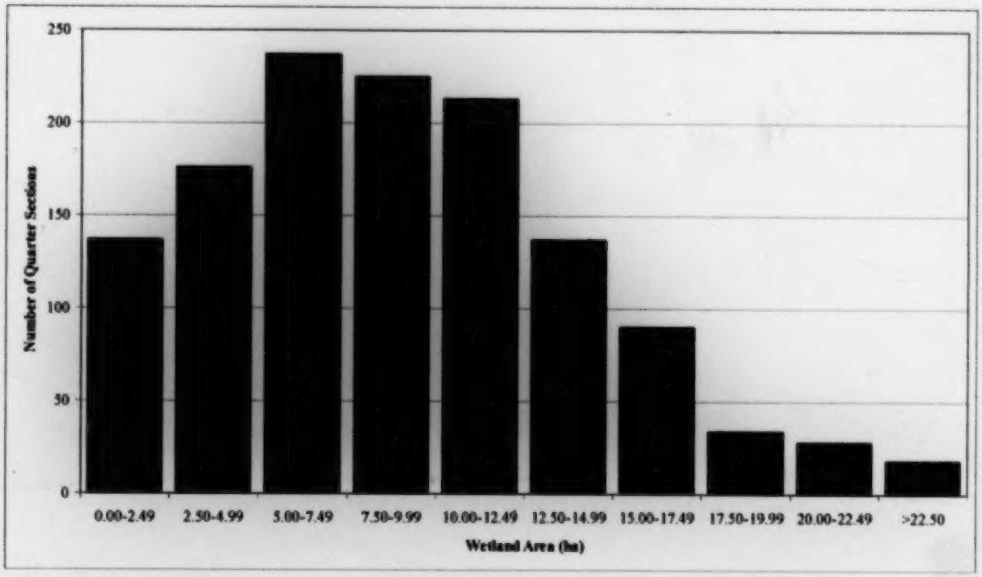
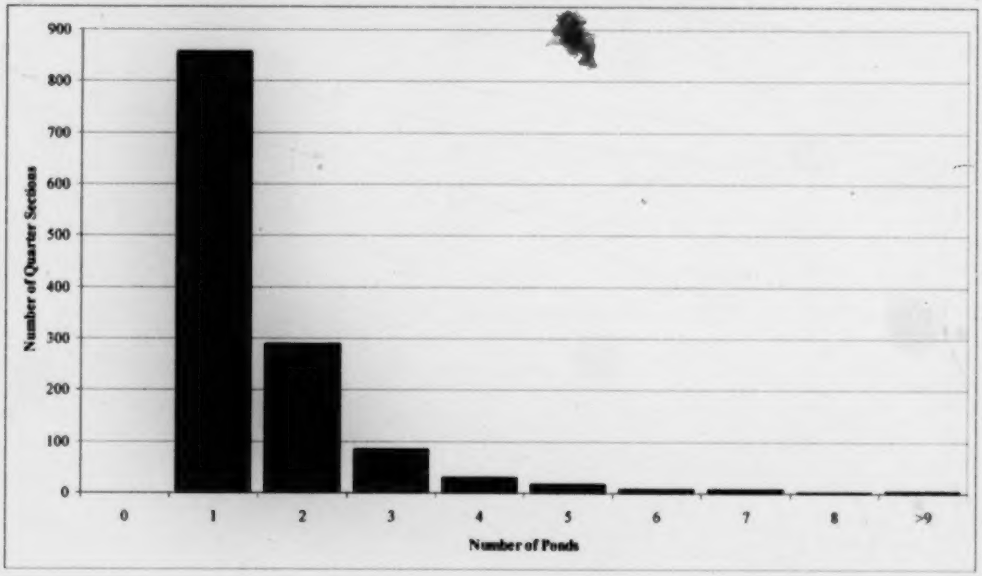


Figure 3.5 – Histogram of wetland counts for quarter sections in the RM of Emerald



basins that comprised 1,264 ha and 6,055 previously drained wetlands. The field with the most cropped basin area had 12.75 hectares of cropped basins, while 80 was the largest number of cropped basins within any particular quarter section. At the other end of the spectrum, 0.001 ha was the lowest area of cropped basins in an individual field, whereas 1 was the fewest number of cropped basins in any particular field.

Establishing the area of previously drained wetlands required estimation since the total area that was once wetlands could not be captured through the aerial photographs used to create these data. Estimation of an approximate area of wetlands that once existed in the RM of Emerald was accomplished through linear regression. Data were obtained for another area in Saskatchewan within the RMs of Churchbridge and Langenburg (RMs 211 and 181, respectively in Figure 3.3) for two points in time, 1957 and 2000. These RMs lie along the Saskatchewan-Manitoba border, east of Emerald and slightly south. This data source is considered to have the best approximation of the initial endowment of wetlands in Saskatchewan (Boychuk, 2005b). The following equation was developed and estimated using the Churchbridge and Langenburg data:

$$WetArea_i = \vartheta_0 + \vartheta_1 \Delta Ponds + \vartheta_2 Drainage + \varepsilon_i, \qquad (3.1)$$

where $WetArea_i$ represented the initial area of wetlands (1957) on the i^{th} quarter section, $\Delta Ponds$ was the change in the number of ponds between 1957 and 2000, *Drainage* was the length of drainage ditch constructed on the quarter section between 1957 and 2000, the ϑ s were parameters to be estimated, and ε_i was an error term. Only those quarter sections that had drainage in the year 2000 were used in the regression. Quarter sections that had significant loss in wetland numbers and area where no drainage data were captured were excluded because their inclusion would negatively impact the estimated coefficient of the drainage variable. The resulting sample included 421 quarter sections that had drainage ditches out of a total of 654. Results of the regression are in Table 3.1. The results indicate that greater lengths of drainage ditch and larger decreases in the number of ponds would be associated with quarter sections that historically had significant wetland area.

Table 3.1 – Initial endowment of wetlands estimation results

Variable	Estimated Coefficient
Drainage	2.7421*** (0.0247)
ΔPonds	-0.0915*** (0.3907)
Constant	3.8547*** (0.6350)
R^2	0.2566
Standard Error	6.0137
No. of Records	421

Notes: * Represents significance at the 10% level, ** at the 5% level and * at the 1% level. Heteroskedasticity was adjusted for using White's heteroskedastistic-consistent covariance matrix. Standard errors are in brackets.**

Utilizing equation 3.1 with an expected value of zero for the error term, it was estimated that about 6,276 ha of wetland were drained on the 959 quarter sections in the RM of Emerald. To put these wetland figures into perspective, they suggest that about

41% of the original wetland area on these quarter sections has been drained. This figure is nearly identical to the provincial average of 40% (Huel, 2000).

3.4 Chapter Summary

The study area, the RM of Emerald, lies in east-central Saskatchewan and is part of the Prairie Pothole Region. The Prairie Pothole Region is known for its importance as a breeding ground for waterfowl. The RM lies within a productive agricultural area in Saskatchewan and wetlands in this area impose nuisance costs on farm operators and represent opportunities to increase their cultivated land base. Wetlands in the RM of Emerald are therefore at risk of being converted to agricultural uses. Organizations interested in conserving wetlands in this area need to consider the value of wetlands as agricultural land in order to develop instruments to protect them.

An analysis of drainage activity in the RM of Emerald needs to represent the farming practices in the area. Census of Agriculture statistics and soil survey data indicated that the study area lies in the black soil zone and most of the area within the RM is suitable for producing cash crops. Significant amounts of major Western Canadian cash crops in this area are grown, including wheat, barley, oats, and canola. Farms in this area continue to use summerfallow in their rotations, though the practice is declining. No-till practices are also common among farm operators in the RM. Livestock numbers in the area are not significant. The analysis should therefore be conducted for a cash crop operation that summerfallows land occasionally, utilizes no-till practices, and is not diversified into livestock production.

Other data reveled that significant amounts of drainage infrastructure are present in the RM of Emerald. Drainage projects conducted in the study area are mostly surface projects carried out by farm operators using their own equipment and this type of drainage will be analyzed in the model. No data exist, however, that indicate the amount of land drained in the RM of Emerald. Estimating the amount of land indicated that it has lost about 41% of its original wetland area. This estimate becomes important when analyzing drainage from a historical perspective.

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Chapter 4: Theoretical Model

An overview of the theory utilized in the present study is provided in this chapter. Capital budgeting techniques were employed since drainage is an investment decision. Simulation was also used in the analysis since its flexibility allowed incorporation of several complex relationships associated with drainage. An outline of the structure of the model developed for the present study is also provided along with a description of the method used to determine the discount rate used in NPV analysis. The chapter concludes with a discussion on utilizing simulation analysis in conjunction with capital budgeting.

4.1 Capital Budgeting

Capital budgeting was used in the present study since drainage is an investment decision. Undertaking wetland drainage may require an initial investment in equipment, with resulting impacts on cash flows over an extended period of time. Economic theory would suggest that decisions of this sort be made on the basis of capital budgeting in order to be consistent with an assumed objective of wealth maximization.

Investment decisions are often made using one of four capital budgeting techniques: net present value (NPV), internal rate of return (IRR), the payback period (PP) and the accounting rate of return (ARR) (Copeland et al., 2005). According to Copeland et al. (2005), NPV is calculated by discounting future cash flows using an appropriate discount rate that reflects the required rate of return that must be generated by the project. This required rate of return, or opportunity cost, in turn should reflect the level of risk involved in the project. Any projects that have positive NPVs are economically feasible. The following equation, taken from Copeland et al. (2005), shows the basic computation involved:

$$NPV = \sum_{t=1}^{N} \frac{CF_t}{(1+k)^t} - I_0, \tag{4.1}$$

where CF_t represents net cash flows in time period t, I_0 is the present value of the initial cash outlay, k is the discount rate or opportunity cost of capital, and N is the number of years in the project's expected lifetime.

The IRR, as defined by Copeland et al. (2005, p.28) is the "rate which equates the present value of the cash outflows and inflows," or the rate which makes the NPV equal to zero. The computed IRR for the project is then compared to the opportunity cost of capital; projects with IRRs that are greater than the opportunity cost of capital are economically feasible (Copeland et al., 2005). The IRR equation is almost identical to the NPV calculation. The basic formula, taken from Copeland et al. (2005), is as follows:

$$NPV = 0 = \sum_{t=1}^{N} \frac{CF_t}{(1+IRR)^t} - I_0. \tag{4.2}$$

The third capital budgeting technique, the PP, is simply defined as the number of years it takes to recover the initial investment in the project. The decision rule with the PP method is to accept the project with the shortest PP or those projects with a PP shorter than a predetermined value (Copeland et al., 2005).

The last technique, the ARR, "is the average after-tax profit divided by the initial cash outlay (Copeland et al., 2005, p.28)." The ARR computation from Copeland et al. (2005) is shown below:

$$ARR = \frac{ATP}{IO}, \tag{4.3}$$

where ATP is average after-tax profit and IO is initial outlay. ATP is calculated by adding the expected after-tax profits over the lifetime of the project and dividing it by the number of years in the project's expected life (Copeland et al., 2005).

The problem of determining which of the techniques is most appropriate has been addressed in the literature. The basic question is in regards to which technique is most consistent with wealth maximization (Copeland et al., 2005). Copeland et al. (2005) address this problem by asking the following four questions:

1. Are all cash flows considered?
2. Are the cash flows discounted at the appropriate opportunity cost of capital?
3. Does the technique select the project that maximizes wealth from a set of mutually exclusive projects?
4. Are the managers able to consider one project independently from all others?

Comparison of NPV, IRR, PP, and ARR according to the above criteria reveals that NPV should be used as it is the only one that satisfies all of the above criteria. Examination of the other capital budgeting techniques demonstrates that the PP technique only considers cash flows up until the project recovers the initial investment, while the ARR does not consider the time value of money, and the IRR assumes that the investor can reinvest their money at the IRR of the project instead of the opportunity cost of capital (Copeland et al., 2005). Therefore, NPV was the capital budgeting technique used in the simulation analysis. Farm operators performed an NPV analysis of the possible drainage projects that could be completed on their land and then undertook those projects that yielded positive NPVs. Net present value analysis was also be used to determine the overall economic feasibility of investing in drainage infrastructure.

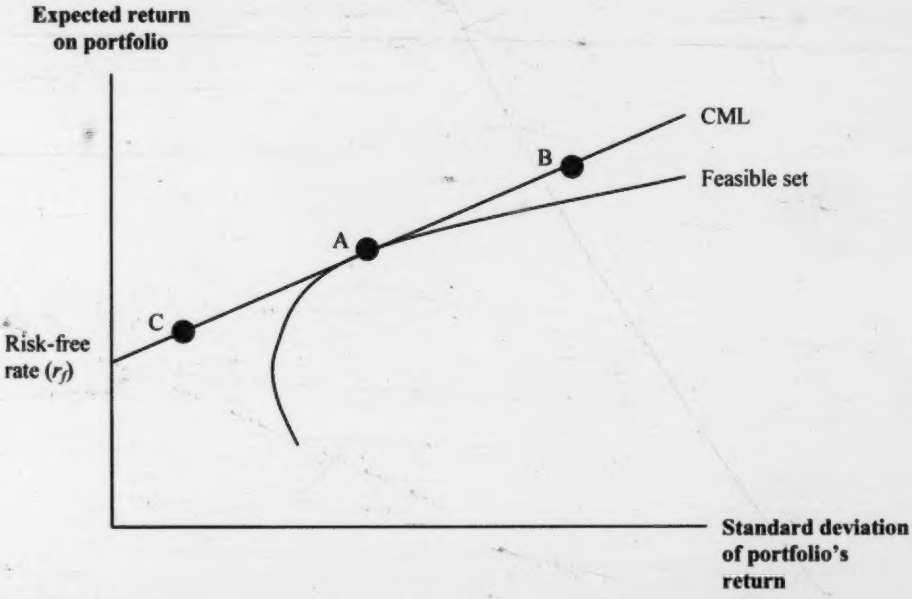
4.1.1 Determining Discount Rates for Net Present Value Analysis

The discount rate is the rate at which future cash flows are discounted in an NPV analysis. The discount rate should reflect the opportunity cost associated with the capital being invested in a project. In order for an investment to be sufficiently profitable, it should earn at least as much as the best alternative opportunity for using that capital.

In determining whether to invest in a risky project such as drainage, Ross et al. (2003, p. 244) state that "investors will only hold a risky security if its expected return is high enough to compensate for risk." Therefore, the discount rate used in NPV analysis reflects the level of risk involved in the project. Riskier projects should be associated with higher expected returns and therefore higher discount rates should be used for evaluating such projects (Ross et al., 2003). The Capital Market Line (CML) is a method used to calculate expected returns that incorporates the total risk of a project. Figure 4.1, adapted from Ross et al. (2003), illustrates CML theory.

In Figure 4.1, the feasible set represents all possible combinations of risky securities, or portfolios that may be held by an investor. As anticipated, the standard deviation of the portfolio's return rises as the expected return on the portfolio increases. The main purpose of the illustration is to demonstrate that only one portfolio of market securities is optimal when making investments in the market in combination with investments at the risk-free rate. The optimal portfolio is that which lies on a line from the risk-free interest rate and is tangent to the feasible set (point A). This line is the Capital Market Line. Theory states that the optimal portfolio can be determined without any prior knowledge of an investor's degree of risk aversion and implies that all investors will hold the same combination of risky securities (Ross et al., 2003; Sharpe et al., 2000). With risk-free borrowing and lending, investors with different degrees of risk aversion will choose to invest at different points on the CML (Sharpe et al., 2000). A more risk averse investor will choose a point such as point C, while an investor with a lower degree of risk aversion will borrow additional funds and choose to invest at a point such as point B (Ross et al., 2003).

Figure 4.1 – Capital Market Line theory


Expected return on portfolio
CML
B
Feasible set
A
C
Risk-free rate (r_f)
Standard deviation of portfolio's return

CML uses the market as the opportunity cost of investing in the farm operation. If the level of risk for such an investment could be determined, the use of CML would provide an indication of the level of expected returns that would be required for such an investment to be worthwhile. This level of expected return is then used as the discount rate for NPV analysis. The equation for calculating expected returns utilizing CML from Sharpe et al. (2000) is as follows:

$$\bar{r}_p = r_f + \left[\frac{\bar{r}_M - r_f}{\sigma_M}\right]\sigma_p, \tag{4.4}$$

where $\bar{r}_p$ was the expected return of the farm operation, σ_p was the standard deviation of the farm operation's returns, r_f was the risk-free interest rate, $\bar{r}_M$ was the expected return from the market portfolio, and σ_M was the standard deviation of the market portfolio. In calculating expected returns, the return on government issued treasury bills is often used as the risk-free interest rate and the return on an index such as the Toronto Stock Exchange (TSE) is used as the expected return in the market (Ross et al., 2003).

4.2 Simulation Analysis

Simulation was the analytical tool used for this study. Simulation analysis was chosen as opposed to optimization or traditional NPV analysis of previously conducted projects. Optimization is more structured than simulation and could have imposed restrictions on the model that would not have allowed for the inclusion of certain components. A traditional NPV analysis of previously conducted projects was ruled out because it was determined by DUC that there was a lack of reliable data.

Evans and Olson (2002, p. 2) define simulation as "the process of building a mathematical or logical model of a system or a decision problem, and experimenting with the problem to obtain insight into the system's behavior or to assist in solving the decision problem." Some of the most appealing characteristics of simulation analysis are flexibility and its ability to incorporate uncertainty (Evans and Olson, 2002). The flexibility of the technique does allow for optimization, though it is not inherently part of simulation analysis. One drawback of using simulation analysis is that models are often very complex and can take a long time to construct (Law and Kelton, 2000). A typical simulation model structure taken from Evans and Olson (2002) is shown in Figure 4.2.

Figure 4.2 – Typical structure of a simulation model

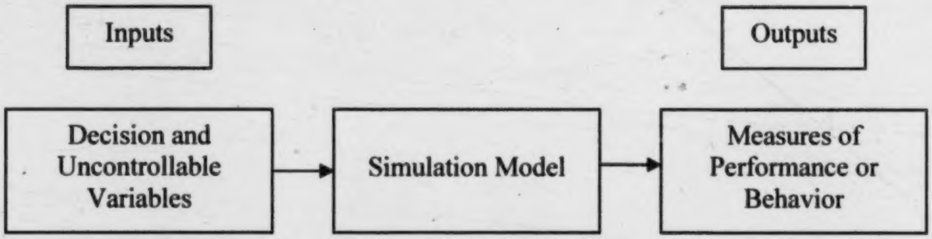

Inputs
Outputs
Decision and Uncontrollable Variables
Simulation Model
Measures of Performance or Behavior

Figure 4.2 is best explained through the use of an example. In crop production, farm operators are concerned with returns from production and do not want to be exposed to too high a risk of negative returns. Decision variables for a farm operator would be crops grown and inputs used (e.g., fertilizer, pesticides, seeds), whereas uncontrollable variables would be weather and prices. Weather influences returns since crop yields are dependent upon growing conditions. The simulation model would have distributions for weather and prices and draw from these distributions to simulate outcomes based on the decisions of the farm operator. The measure of performance would be the net returns from crop production. The process could be repeated to generate a distribution of outcomes and decision variables (e.g. different set of crops) could also be changed in order to determine the impact on net returns. The farm operator could then use the results to determine the appropriate combination of crops grown and inputs used to avoid negative returns.

Monte Carlo simulation is the specific type of simulation used in this study; it is "a sampling experiment whose purpose is to estimate the distribution of an outcome variable that depends on several probabilistic input variables (Evans and Olson, 2002, p. 5)." This form of simulation is commonly used in analyzing risk involved in decision making (Evans and Olson, 2002). Risk is defined by Evans and Olson (2002, p. 5) as the "probability of occurrence of an undesirable outcome." It can also be described by the degree of dispersion exhibited by the distribution (Ross et al., 2003). A limitation of Monte Carlo simulation is that since sampling is used, the results will be subject to sampling error (Evans and Olson, 2002; Law and Kelton, 2000)[27]. However, through the use of a large number of iterations (1,000 to 10,000), sampling error can be minimized (Evans and Olson, 2002). Today's computers are generally able to perform such tasks over relatively short periods of time.

Due to the flexibility of simulation analysis, it is used in all types of research. Several simulation analyses have been conducted in the context of wetland drainage including Heimlich et al. (1998), Kramer and Shabman (1993), and McColloch and Wissman (1988). Textbooks on simulation analysis emphasize how extensively it is used by financial organizations and service organizations such as call centers and fast-food restaurants, as well as its uses in modeling production and assembly operations (Evans and Olson, 2002; Law and Kelton, 2000). Some examples of applications of simulation techniques for agricultural and resource issues include: riparian grazing management (Miller, 2002); predicting workdays for farm operations (Elliot et al., 1977); weed management issues (Nordblom et al., 2003; Swinton and King, 1994; Dunan et al., 1994); evaluation of farm safety net programs (Jeffrey and Novak, 1999); crop growth models (Chipanshi et al., 1999); agroecosystem sustainability (Belcher et al., 2004); and analysis of risk in livestock industries (Hotz, 2004; Perillat et al., 2004).

4.2.1 Conceptual Simulation Model

The present study deals with analyzing the returns to drainage for a typical farm in the RM of Emerald. The model needed to simulate the operations (e.g., crop production, participation in government programs) of a farm to determine its performance. The model was also required to be capable of simulating how farm operators would make decisions on which drainage projects to undertake and how these projects were conducted. In order to determine whether drainage improved farm performance, the decision to drain land needed to be compared to an alternative where the farm operator did not drain land. The model also needed to be sufficiently flexible to allow for different decisions made by a farm operator regarding farm practices, participation in farm programs and drainage decisions. This flexibility permitted scrutiny of the effects of various decisions a farm operator could make that influence the outcomes of the analysis.

Determining farm performance required modeling economic relationships pertaining to a farm. A farm derives revenue from sales of crops and payments received through participation in farm programs. There are numerous expenses associated with operating a farm. However, only those that differed between the two alternative actions analyzed (i.e. investing in drainage or not) needed to be included in the analysis.

A dynamic analysis was required since completion of the type of drainage undertaken in the RM of Emerald requires more than one year. Several years of benefits and costs related to drainage projects conducted also needed to be utilized in order to establish whether drainage would be economically feasible.

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[27] Daniel and Terrell (1992, p. 814) define sampling error as "the difference between an estimate and the true value of the parameter being estimated."

Risk was important to the analysis, as farm performance is influenced by several factors that are beyond the control of a farm operator. For example, farm operators do not have any control over the price received for their crops. Due to global supply and demand relationships and farm subsidies, the prices received for crops can exhibit a high degree of variability from year to year. Stochastic variables needed to be utilized to represent such factors. Discounting of returns was also employed to account for risk.

Biophysical relationships were also modeled in the simulation. Local weather directly affects crop yields experienced by a farm operator. Therefore, weather served as determinants of crop yields in the analysis. Drainage may also have an impact on crop yields and it would be important to include this relationship in the analysis.

Modeling drainage required knowledge of how drainage projects were conducted in the RM of Emerald. Cost and benefit streams resulting from undertaking drainage projects were identified and modeled. Additional equipment requirements were identified and scenarios were developed to incorporate these costs into the analysis. The analysis also needed to simulate a possible decision making process a farm operator could employ when determining whether to invest in drainage.

4.2.2 Resulting General Model Structure

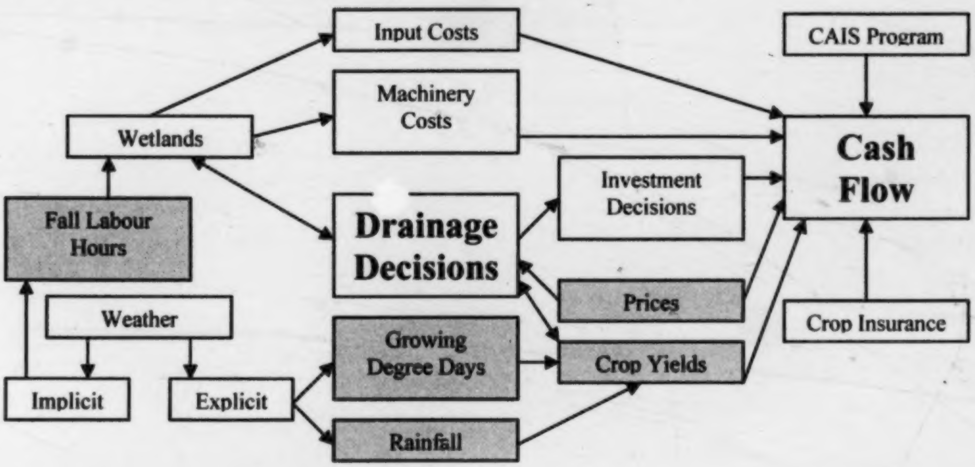
Figure 4.3 is a diagram indicating the conceptual model structure in terms of its components and the relationships between them included in the analysis. Two main components of the simulation were those that dealt with calculation of cash flows and modeling of drainage decisions. Growing degree days, precipitation, fall labour hours, crop yields and prices were all estimated and incorporated as stochastic variables. Crop yields were modeled so that they were influenced by growing degree days and precipitation. Commodity prices and crop yields were modeled to have an effect on both drainage decisions and cash flows. For example, periods of high prices and above average crop yields would increase returns to drainage and provide an incentive to drain more wetlands. High prices and above average crop yields would also increase farm revenues and improve cash flows.

Drainage decisions made by the farm operator would decrease numbers of wetlands and total wetland area on the farm operator's land, and increase their cultivated land base. Drainage may also increase crop yields, since crops may yield better on drained lands. If a farm operator did decide to drain wetlands, investment in drainage equipment may be necessary. Investing in drainage equipment would reduce cash flows. However, the amount of drainage conducted each year may be limited by fall labour hours available to devote to drainage projects and this was influenced by weather.

Nuisance costs of wetlands were represented by the relationship between wetlands and machinery and input costs in Figure 4.3. Draining wetlands reduced these nuisance costs and improved cash flow. Reductions in nuisance costs were included in drainage decisions made by the farm operator.

Participation in farm programs, specifically crop insurance and the Canadian Agricultural Income Stabilization (CAIS) program, would also impact cash flows. These programs increased cash flows in years of poor performance. They also required some form of reduction in cash flow if a farm operator chose to participate in them. Farm operators pay premiums to participate in crop insurance and are required to deposit funds in an account to enroll in the CAIS program.

Figure 4.3 – Modeled relationships between simulation components



Note: Grey components are stochastic.

4.3 Using Simulation Analysis for Capital Budgeting Problems

Vlahos (1997) promotes the use of simulation analysis for making investment decisions. Traditional cash flow models only calculate a single, potentially misleading NPV to base investment decisions on, while Monte Carlo simulation models yield a distribution of NPVs (Vlahos, 1997). According to Vlahos (1997), the NPV distribution provides more information than static cash flow models, but understanding of probabilities and common sense are needed to make good use of this additional information. Users of the information should spend time to develop an understanding of the uncertainties, take steps to reduce them and form strategies to cope with downside risk (Vlahos, 1997).

On the other hand, there has been some criticism of the use of simulation analysis for capital budgeting. Simulation incorporates risk through the use of stochastic variables, whereas NPV analysis incorporates risk through the use of a risk-adjusted discount rate. According to Trigeorgis (1999), by accounting for risk through the use of stochastic variables and a discount rate, the meaning of the distribution for NPV becomes questionable because it is not clear what discount rate should be used (Trigeorgis, 1999). Myers (1976) found that if NPV analysis is conducted using an appropriate discount rate, then further risk adjustments result in double-counting. On the other hand, if one used a risk-free rate of interest instead of a risk adjusted discount rate, then the NPV distribution represents the project's value if all uncertainty regarding the project were resolved between today and tomorrow (Myers, 1976). Uncertainty does not get resolved in this way; therefore, the meaning of the NPV distribution is unclear (Myers, 1976). Despite these issues, Trigeorgis (1999) states that simulation is still an appropriate tool for use with NPV analysis. However, Trigeorgis (1999) recommends the use of the distribution of cash flows to determine a single NPV for decision making.

4.4 Chapter Summary

Net present value analysis in a Monte Carlo simulation was used to study wetland drainage in Western Canada. NPV analysis was chosen over other techniques because it has been shown to be most consistent with wealth maximization, whereas simulation analysis was employed since it enabled scrutiny of several factors that could potentially impact the economic feasibility drainage. A discussion on CML theory revealed that determining whether drainage projects should be undertaken involves analyzing the returns to drainage relative to returns received in other investments.

An overview of the research problem and the results of the literature review revealed the relationships that needed to be modeled. The problem to be modeled is whether expanding one's land base through drainage improved farm performance relative to not draining land. Therefore, revenues and costs for a complete grain operation were modeled to analyze the economics of drainage. Due to the nature of drainage projects, the simulation was conducted over several years and included stochastic components and discounting to account for risk. Biophysical relationships, such as the influence of weather on crop yields, were also included in the analysis. Finally, the type of drainage used in the study area needed to be simulated using appropriate costs and benefits.

The model included stochastic variables for growing degree days, precipitation, fall labour hours, crop yields and commodity prices. These variables were modeled to impact drainage decisions and cash flow. If the farm operator decided to undertake drainage projects, wetlands would be removed from quarter sections increasing a farm operator's cultivated land base and reducing nuisance costs that arise from maneuvering equipment around wetland obstacles. Participation in farm programs was also modeled to impact cash flows.

A discussion on using simulation analysis for capital budgeting problems revealed some issues that researchers should be aware of. Simulation analysis provides a researcher with more information than traditional cash flow models. On the other hand, double-counting of risk has been revealed as a problem of using the two techniques together.

Chapter 5: Empirical Simulation Model

A detailed description of the simulation model developed to analyze wetland drainage in the RM of Emerald is presented in this chapter. The simulation was a stochastic dynamic model that simulated the performance of a representative farm over a 20-year period. The model was programmed using @Risk©. The @Risk© software was chosen for the present study because of its compatibility with Microsoft Excel©. Weather, crop yields, commodity prices, and time available to conduct drainage projects were incorporated as stochastic elements. Each simulation performed utilized the same set of random draws for the stochastic variables, which enabled comparisons across simulations.

One thousand iterations were used to generate distributions of outcomes to base conclusions on. To determine the number of iterations needed, simulations of 5,000 iterations and 1,000 iterations were performed. Comparing the results from the two simulations indicated that the differences were not significant; therefore 1,000 iterations were used[28].

The simulation calculated NPVs based on cash flows the farm experienced over the 20-year period. In each simulation, calculations were performed for the farm if it were to maintain its existing cultivated land base and if it were to expand its cultivated land base through drainage. Cash flows were not modeled so that outcomes in one year would impact decisions made in the following years. This means that cropping and input decisions and decisions to participate in farm programs were not affected by previous years' performance. Thus, the farm operator followed the same crop rotation, used the same inputs for each crop, and made the same decisions regarding farm programs for each year of the simulation. It was also assumed that the farm operator did not change their machinery complement over the 20-year simulation period because additional cultivated land obtained through drainage was deemed insufficient to warrant an increase in machinery size. Since the comparison farms were identical, their debt structure was also the same. Therefore, since fixed costs did not differ between the two alternative actions, they were not included in the analysis.

The calculations determined which strategy, increasing the cultivated land base through drainage or maintaining the existing cultivated land base, provided greater returns. The actions of the farm operator over the simulation period also provided insight into the value of drained land and the amount of wetland area potentially at risk of drainage. Outputs for the value of drained area to farm operators were used to develop policy instruments for wetland conservation.

5.1 Representative Farm Characteristics

The composition of the representative farm used in the present analysis is discussed in this section. A representative farm is a typical farm within the study area. The parameters for the representative farm were developed based on data available for the area and expert opinion, and reflected observed farming practices in the RM of Emerald.

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[28] Results of this test are available in Appendix F.

5.1.1 Land Base

The representative farm was comprised of quarter sections from the RM of Emerald. One hundred quarter sections were randomly selected from data provided by DUC for the study area and were utilized in the simulation model (Boychuk, 2005b). These quarter sections, however, were filtered so that quarter sections mostly comprised of areas other than cropland or wet areas were not eligible to be used in the simulation[29]. The quarter sections removed were those that contained greater than 5 ha of forage, grassland, roads, wooded areas, and farmyards. Any remaining area of these components was considered cropland. Roads, wooded areas, and farmyards were other obstacles that could result in increased costs to the farm operator. The project was intended solely to measures benefits and costs of wetland drainage. Including costs incurred because of other obstacles could obscure results regarding drainage benefits and costs. Forage and grassland areas were not considered for use in the simulation as these are not typically cash crops.

Filtering the data reduced the number of quarter sections eligible for use in the simulation to 625. The 100 quarter sections used in the model were chosen from these 625 quarter sections through a stratified sampling procedure. The 625 quarter sections were stratified based on an index of wet area. This index was comprised of the sum of wetland hectares, cropped basin hectares, the number of wetland areas, and the number of cropped basins. Quarter sections with a higher index had higher values for wet area counts and hectares of wet areas. Once each quarter section was given an index, the 625 quarter sections were stratified into four quartiles and twenty-five fields were then selected from each of the four quartiles to yield the 100 quarter sections used in the simulation. Comparisons of wetland area and counts for the quarter sections used in the simulation model relative to wetland area and counts for all the quarter sections within the RM of Emerald are provided in Figures 5.1 and 5.2. The figures suggest that the quarter sections used in the simulation are representative of the quarter sections in the RM of Emerald. The sampled quarter sections had mean values for wetland area, wetland counts, cropped basin area, and cropped basin counts of 7.97 ha, 1.84, 1.71 ha, and 14.17, respectively. Maximum values for the same variables were 24.96 ha, 13, 11.37 ha and 52, respectively and minimum values were 0.25 ha, 1, 0.01 ha and 1, respectively.

Relevant information needed to perform the model calculations was provided for each quarter section. This included cropland area, existing drainage infrastructure, previously drained areas estimated using equation 3.1, area of cropped basins and wetlands and their respective counts, and length of drainage ditch required to drain the quarter section. Machinery costs for each parcel were also calculated for non-harvest machinery activities (i.e. activities other than combining and swathing) and summerfallow activities before and after drainage. Times for swathing and combining were calculated as well for both before and after drainage, as these were needed to determine the time a farm operator had available for drainage activities.

The percentage of cropland owned by a farm operator was important to the present study since research findings revealed that farm operators usually do not make capital improvements to rented lands (van Vuuren, 1994; Morris and Hess, 1986). The percentage of land owned used in the model was 75%. This value was the average for the RM of Emerald from the 2001Census of Agriculture (Biggs, 2004).

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[29] The term "wet area" refers to wetlands and cropped basins.

Figure 5.1 – Comparison of wetland area for quarter sections used in the simulation model relative to the RM of Emerald

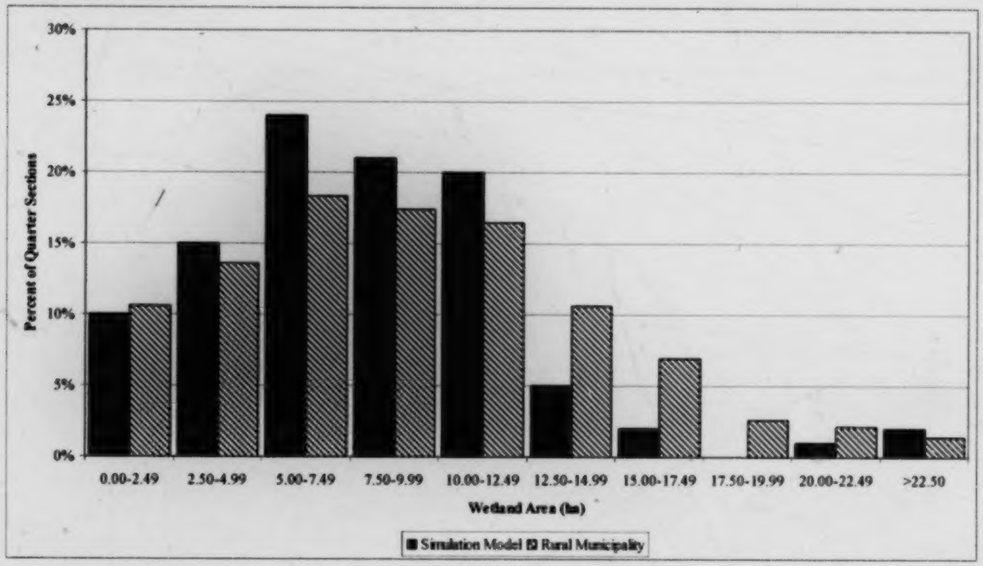
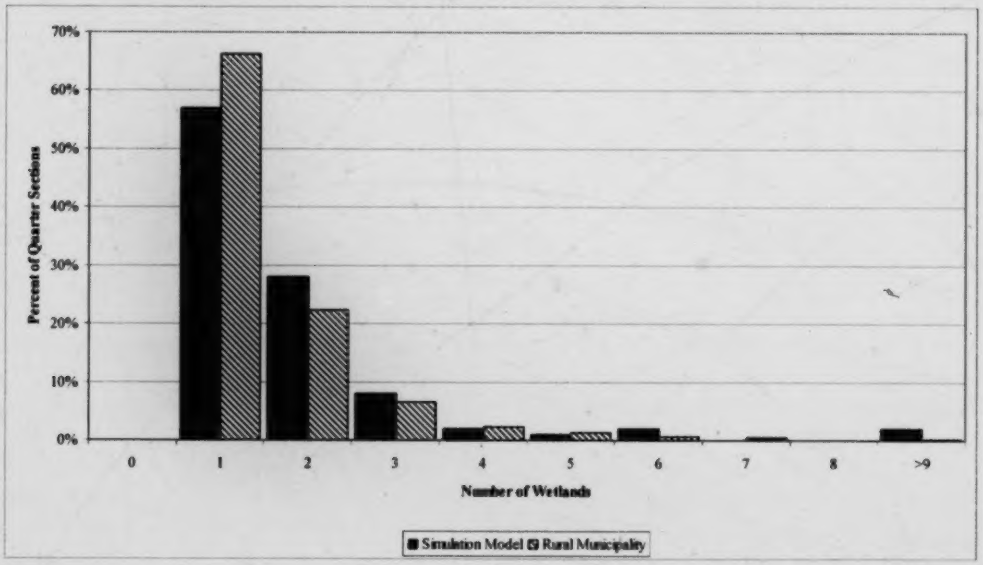


Figure 5.2 – Comparison of wetland counts for quarter sections used in the simulation model relative to the RM of Emerald



5.1.2 Farm Size

Farms in the RM of Emerald vary in size; thus different sized representative farms were considered for the analysis. The model allowed analysis of farms comprised of 4-20 quarter sections in increments of four quarter sections to represent the various sizes of farms within the study area as described in section 3.3[30]. Average yearly revenues for farms comprised of 4, 8, 12, 16 and 20 quarter sections in the simulation model were approximately $70,000, $140,000, $205,000, $275,000 and $340,000, respectively. Four quarter sections was slightly larger than what would be required to reach $50,000 in sales, but Census of Agriculture data for 2001 indicated that smaller farms were disappearing and larger farms were gradually moving into higher sales classes. Therefore, there was less emphasis on small farms within the analysis. As mentioned in section 3.3, about half of the farms were quite small with sales of less than $50,000 and the majority of the other half had sales between $50,000 and $250,000. Due to wetlands in many of the quarter sections, most had cropland less than the full 64.75 ha that comprises a quarter section. Different crop rotations would also impact how large a farm would need to be in order to reach different levels of sales.

The quarter sections that initially comprise the farm can be fixed or random over the simulation period. The fixed initial land base scenario involved randomly drawing quarter sections from the 100 selected for the analysis and using those same quarter sections throughout the simulation. The random scenario involved selecting a different set of quarter sections from the 100 selected for the analysis for each iteration. The random scenario was developed for the present study because the economic feasibility of drainage was largely dependent on the characteristics of the land. Allowing the quarter sections to change during each iteration removed a bias that could be caused by the random process used to choose quarter sections for a farm with a fixed land base. For example, if the quarter sections chosen for the representative farm were all among those that had low costs per hectare drained, then drainage would appear more attractive than if the farm was comprised of quarter sections that were more typical of the mix of quarter sections in the study area.

5.1.3 Machinery Complements

Each of the different sized farms was assumed to have a different machinery complement. This influenced machinery costs as well as the time taken to perform field operations on each quarter section. It was assumed that each farm used no-till practices since no-till and conservation practices were utilized on 45% of the tilled area in the RM of Emerald in 2001 and the use of no-till practices has been increasing (Biggs, 2004)[31].

Two alternative options were considered for determining the machinery complements for each farm size. An optimal machinery complement can be determined using existing machinery selection algorithms or an ad-hoc selection can be performed based on the field operations required, the farm size, and farm operator time available. The ad-hoc alternative would provide a sufficient machinery complement to perform the necessary field operations.

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[30] Another method of developing a representative farm would be to use a consensus farm, where a group of farm operators is collectively asked to construct a typical farm for their area (Gray et al., 1996).

[31] Between 1996 and 2001 the area under conventional tillage practices fell 2% in the RM of Emerald, whereas the area under no-till practices increased 369% (Biggs, 2004).

Different machinery selection programs, Rotz et al. (1983) and Siemens et al. (1990), were researched based on advice from Alan Rotz to determine whether or not they could be incorporated into the analysis (Rotz, 2004). However, the appropriate data for the study area were not available in order to utilize these programs and an optimal machinery complement was probably not necessary for this research. Rotz et al. (1983) also mentioned that farms appeared to possess larger machinery complements than the optimal and thus utilizing an optimal machinery complement in the simulation would not necessarily replicate reality. Regarding data requirements, both of the studies described models that required information on time constraints for each cropping operation and the cost of untimely operations. Though Baier (1973) has information on average numbers of workdays for different crop growth stages, and this study was used for determining another component of the simulation, there were no data available regarding the cost of untimely operations for Canada.

An ad-hoc machinery selection method was used to determine the machinery complement in the present analysis because of the issues discussed regarding existing machinery selection programs. The machinery complement for each farm size was established by determining the field operations necessary for the tillage system chosen, considering the time available to perform field operations for the area to be covered, and allowing for the possibility that weather conditions could reduce the time available for field operations in certain years.

The 2004 version of Saskatchewan Agriculture, Food and Rural Revitalization's (SAFRR) biennial Farm Machinery Custom and Rental Rate Guide was used to determine the machinery complement for each farm size (SAFRR, 2004d). The machinery complements are shown in Table 5.1. Decisions on implement sizes for each farm were based on meeting the middle annual hours of use value from the annual hours of use table for each implement as listed in the Farm Machinery Custom and Rental Rate Guide (SAFRR, 2004d). Work rates listed in the guide and farm size were used to determine the annual hours of use. For example, when selecting a seeder for a farm comprised of 12 quarter sections, the width of a seeding implement needed was determined using the work rates for the various widths of seeding implements listed within the Farm Machinery Custom and Rental Rate Guide (SAFRR, 2004d). In order to be selected for use in the model, the width of the seeding implement needed to be able to seed all 12 quarter sections at approximately the middle annual hours of use for that implement.

Tractors were then selected on the basis of horsepower needed for the various farm operations. Seeding implements required the most horsepower. Therefore, this was the basis on which the size of the primary tractor was chosen. The decision for the size of the second tractor, where applicable, was based on the horsepower needed to pull one of the other implements. For example, the farm comprised of 12 quarter sections was given a 170 h.p. and a 55 h.p. tractor because the seeding implement chosen required a 170 h.p. tractor and this same size of tractor could be used to pull the sprayer, breaking disk, and scraper. The second tractor, therefore, was only used for swathing and a 55 h.p. tractor was all that was required for this implement. With regards to the 16 and 20 field farms, large four wheel drive tractors were chosen because of high horsepower requirements for the seeding implements selected. It was deemed that the primary tractor would not be used for the other farming activities since the horsepower of the primary tractor was well beyond the requirements for pulling the other implements. The horsepower of the secondary tractor for these farm sizes was based on requirements needed for the scraper, although the large sprayers selected for these farms require significant horse power as well.

Table 5.1 –Equipment complements by farm size

Powered Equipment	Number of Quarter Sections				
	4	8	12	16	20
Tractor 1	150 h.p.	150 h.p.	170 h.p.	275 h.p.	400 h.p.
Tractor 2	-	-	55 h.p.	170 h.p.	170 h.p.
Swather	20 ft,	24 ft.	24 ft.	30 ft.	36 ft.
Combine[a]	Class 5	Class 5	Class 6	Class 7	Class 7+

Drawn Equipment	Number of Quarter Sections				
	4	8	12	16	20
Seeder	20 ft.	24 ft.	30 ft.	40 ft.	50 ft.
Sprayer	60 ft.	95 ft.	110 ft.	110 ft.	110 ft.
Swather	-	-	24 ft.	30 ft.	36 ft.
Breaking Disk	10 ft.	10 ft.	14 ft.	14 ft.	14 ft.
Scraper	6.5 yard	6.5 yard	8.5 yard	8.5 yard	8.5 yard

Note: [a] Descriptions of combine classes are available in SAFRR's Farm Machinery Custom and Rental Rate Guide (SAFRR, 2004d).

Machinery complement assumptions were validated using Census of Agriculture 2001 data (Biggs, 2004). Though Census of Agriculture data do not provide information on implement widths, tractor horsepower information was collected. Based on the little information available for validation, the machinery complements seemed appropriate for the purposes of this research.

5.1.4 Crop Rotations

Crop rotations of three, four, and five years were developed with the assistance of SAFRR (Novak, 2005). These rotations reflected sound agronomic practices and consisted of the crops predominantly grown in the study area. The crops included in the 4-year rotation were, in rotational order: canola, barley, flax, and spring wheat. Substantial areas of all these crops were grown within the RM, with the exception of flax, as indicated by the 2001 Census of Agriculture (Biggs, 2004)[32]. However, without flax in the rotation, cereals would be planted in succession, which is not agronomically sound. Field peas are a substitute for flax, but due to a paucity of data for estimating price and yield equations, flax was used in the present analysis. The 2001 Census of Agriculture showed that both flax and peas comprised similar cropped area within the RM (Biggs, 2004). Peas, however, will likely continue to increase its share of cropped area, as has been the trend in most areas of Saskatchewan. The 5-year rotation was identical to the 4-year rotation; the only difference was that summerfallow followed wheat. The practice of summerfallowing, though declining, still represented a significant portion (17%) of cropland area within Emerald in 2001; therefore, it was included in the analysis. The 3-year rotation was comprised of (in rotational order): canola, wheat and summerfallow.

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[32] Census of Agriculture data for RM 277 are summarized in Appendix E.

Utilizing these crop rotations, the farm would need to have 221, 150, and 187 ha or 3.41, 2.32, and 2.89 full quarter sections of cropland to reach $50,000 in sales at nominal 2001 prices and average yields for each crop for the 3, 4, and 5-year rotations, respectively. To attain a level of sales of $100,000, a farm would need 442, 300 and 375 hectares or 6.83, 4.63, and 5.79 full quarter sections of cropland; and 1,105, 750 and 937 hectares or 17.07, 11.58, and 14.47 full quarter sections of cropland to achieve $250,000 in sales for the 3, 4 and 5 year rotations, respectively.

5.2 Simulation Model Structure

This section describes the relationships that were important in calculating farm performance over the 20-year simulation period. These relationships included stochastic elements beyond a farm operator's control, revenues and costs incurred by the farm, participation in farm programs, benefits and costs of drainage, how drainage in the RM of Emerald is performed, how drainage decisions were modeled, and how the discount rate was determined for the present analysis.

5.2.1 Stochastic Model Elements

This section presents information pertaining to how the stochastic model elements were estimated, incorporated into the simulation model, and how they were validated and calibrated to represent the study area. The stochastic components of the simulation included: weather, crop yields, commodity prices and the time a farm operator had available to devote to drainage projects[33]. Weather, crop yields, commodity prices and available time can all vary considerably from year to year. Models that could simulate the variability in these variables were important to the present analysis. However, since modeling yields, prices and time was not the main objective of the study, the focus was to develop simple models that provided realistic estimates over time.

Weather, to some extent, impacts all the stochastic elements in the model. Although weather events may influence prices through, for example, widespread droughts in major agricultural regions of the world, this was beyond the scope of the present analysis. Weather, however, does play a significant role in the growth of plants and weather variables were incorporated into the estimation of crop yields. Field operations are also affected by weather and the estimated weather variables were used in determining the time available to conduct drainage projects.

Simple crop yield models are often based solely on weather. Though such simple yield equations are readily available through provincial governments, a model specific to the RM of Emerald was developed. Weather variables were estimated as stochastic variables to be used as determinants of yield. The approach described in this section could be used for any other region where data are available.

For commodity prices, the model was based on provincial data and followed established modeling techniques. Modeling time available for drainage was based on existing studies that estimated probabilities of workdays/non-workdays and number of workdays in different seasons/months of the year in Canada. Once the number of workdays was estimated, farming activities that need to be completed prior to conducting drainage were modeled and residual workdays were used as the time available for drainage activities.

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[33] Data used for estimating weather, yield and prices are in Appendix G.

Once models were estimated for the stochastic model elements, they needed to be incorporated into the simulation model. This process generally consisted of using @ Risk© functions to incorporate distributions account for correlations between variables. For weather variables, the weather data needed to be fitted to appropriate distributions and correlated. The crop yield models and commodity price models required distributions for the error term and a method for estimating the correlation structure among the error terms of the equations. To simulate the time available to conduct drainage, fall workdays were estimated using probabilities and random draws from a distribution.

Calibration and validation of the stochastic model components were performed to confirm that each element performed as expected and were consistent with other data available. For example, it was necessary to check whether the models estimated infeasible values and if means of the distributions approximated those from other data sources. Calibration and validation was performed using simulation analysis. Each component was calibrated and validated separately and then changes were incorporated into the complete simulation model structure.

5.2.1.1 Weather Variables

5.2.1.1.1 Estimation of Weather Variables

Weather variables were included as stochastic variables to serve as inputs into crop yield functions. Precipitation also influenced yields in cropped basins, as it was assumed that yields in these areas would be 0 tonnes/ha when precipitation was sufficiently high. Growing degree days influenced the time available to conduct drainage projects since growing degree days were assumed to determine crop maturity dates. Harvest could not begin until the crop was ripe and therefore little time would be available to conduct drainage in years when growing degree days were low.

Weather data from the two weather stations nearest to the RM of Emerald (located at Wynyard and Kelliher) were provided by DUC staff (Boychuk, 2004). The raw data included daily observations of rain, snow, total precipitation, as well as maximum and minimum temperatures. The Kelliher data series included observations from late 1951 to the end of 2001 and the Wynyard series ranged from the beginning of 1965 to the end of 2001. The Kelliher weather data series was used for the simulation over the Wynyard series for use in the simulation model. The justification for this decision is provided within the crop yield models discussion (section 5.2.1.2.1).

The raw data were converted to growing season precipitation and daily growing degree days. The growing season used was May 15th to August 13th, as indicated in the 1994 Saskatchewan Soils Survey for Emerald (Saskatchewan Institute of Pedology, 1994). The total precipitation variable was simply summed for the days within the growing season to obtain growing season precipitation (*GS)*.

Daily growing degree days (*GDD*) were calculated according to the following equation taken from Corbally and Dang (2002),

$$Max\{0,[(MaxTemp + MinTemp)/2] - K\}, \qquad (5.1)$$

where *K* was the threshold temperature which must be reached for the crop to grow, *MaxTemp* was the maximum daily temperature, and *MinTemp* was the minimum daily temperature. For the crops utilized in the present analysis, 4.44 degrees Celsius was the threshold temperature (Corbally and Dang, 2002). The daily *GDD* values were summed over the growing season to obtain growing degree days for the year.

Simple analyses for the Kelliher data series were then conducted to check for possible autocorrelation within the *GS* and *GDD* variables and for correlation between them. These analyses were conducted to determine whether the distributions for the *GS* and *GDD* variables were independent from each other and from previous time periods. This would have implications for how these variables are modeled within the simulation. The null hypothesis that no autocorrelation exists was not rejected for the *GS* and *GDD* variables at the 5% confidence level, although the p-value for the test on the *GDD* variable was only slightly outside the 5% level (5.6%). There was, however, a significant negative relationship between the *GS* and *GDD* variables; more rain within a growing season resulted in fewer growing degree days. The correlation coefficient between the two variables was -0.30.

5.2.1.1.2 Incorporating Weather Variables into the Simulation

To simulate weather, distributions for the *GS* and *GDD* variables over the growing season were estimated and random draws from each of these distributions were then made to simulate weather in a given year. The distributions for each variable were defined using the "best fit" function in @Risk©. Three tests are used by @Risk© to determine the distributions which best fit the data, a chi-square statistic, the Kolmogorov-Smirinov statistic, and the Anderson-Darling statistic[34]. For each distribution fitted to the data, the results of each test and its ranking according to each test are given. Logistic distributions were the best fitted distributions for both variables. The random draw process in the simulation accounted for the negative correlation of -0.30 between the two variables. Thus, when a high value for the *GS* variable was drawn, the value for the *GDD* variable had a greater chance of being lower.

5.2.1.1.3 Calibration and Validation of Weather Variables

The logistic distribution for growing season precipitation initially estimated negative *GS* values as well as *GS* values well beyond observed values from the Kelliher weather station. This was corrected by specifying upper and lower bounds for rainfall. The upper (400mm) and lower (30mm) bounds for the *GS* variable were established using existing precipitation distributions for the RM of Emerald in the 1994 Saskatchewan Soils Survey (Saskatchewan Institute of Pedology, 1994). Bounds set were also beyond any observed values in the existing data series. Repeated simulations showed that the bounds for the *GS* variable did not affect the mean *GS* value, since they were several standard deviations away from the mean. No bounds were deemed necessary for the *GDD* variable since the calibration results appeared to be representative of the observed values.

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[34] A discussion of these tests is given in Guide to Using @Risk, Version 4.5 (2002).

5.2.1.2 Crop Yield Models

5.2.1.2.1 Estimation of Crop Yield Models

Crop yields were assumed to be a function of weather. Therefore, the simulated weather variables served as inputs into the crop yield models. Crop yields in the RM of Emerald were available through SAFRR (SAFRR, 2004c). Although the data series began in 1938, yearly oilseed yields were not consistently available until the late 1960s. Each crop yield equation was estimated using information from the years 1967 to 2001. This period was the longest data series available with complete yield data for all crops.

Expert opinion regarding soil moisture modeling and crop production functions was sought in order to develop crop yield model specifications. Dr. Paul Bullock (2004), a soil scientist at the University of Manitoba suggested that the ratio of water use to water demand was one of the most significant variables in crop production functions and that time trends and soil moisture available at the beginning of a growing season would not be significant. With the climate data provided, a water use to water demand ratio was developed using growing season precipitation as a proxy for water use and growing degree days as a proxy for water demand. The crop yield equations were specified as quadratic models:

$$\begin{aligned} y_t^C &= \phi_0^C + \phi_1^C \frac{GS}{GDD} + \phi_2^C \left(\frac{GS}{GDD}\right)^2 + \varepsilon_t^C \\ y_t^B &= \phi_0^B + \phi_1^B \frac{GS}{GDD} + \phi_2^B \left(\frac{GS}{GDD}\right)^2 + \varepsilon_t^B \\ y_t^F &= \phi_0^F + \phi_1^F \frac{GS}{GDD} + \phi_2^F \left(\frac{GS}{GDD}\right)^2 + \varepsilon_t^F \\ y_t^W &= \phi_0^W + \phi_1^W \frac{GS}{GDD} + \phi_2^W \left(\frac{GS}{GDD}\right)^2 + \varepsilon_t^W , \end{aligned} \tag{5.2}$$

where C, B, F, and W represented canola, barley, flax and wheat, respectively, ϕ_0 represented a constant, ϕ_1 and ϕ_2 were the coefficients on the linear and quadratic water use to water demand ratio terms, respectively, and the ε terms were errors.

The relationship between precipitation, growing degree days and yield suggested by this model specification would indicate that high values for either of the explanatory variables relative to the other could have a damaging effect on yield. In the Canadian Prairies this is often exemplified by excessive heat and little precipitation. The linear term reflected the fact that increased precipitation relative to growing degree days improves yields, whereas the quadratic term allowed for the damaging effects excessive moisture has on yields.

The final yield equations for each crop were estimated as a seemingly unrelated regression (SUR) system of equations. The purpose of using SUR was to obtain an estimate of the correlations between the errors among the equations for different crops. The results are provided in Tables 5.2 and 5.3. The relationship between the errors resulted in more robust yield estimates within the model and was especially helpful in the case of canola, where the individual equation R^2 was quite low. Since the explanatory variables across the equations were identical, the use of SUR did not lead to improvements in estimates of the coefficients. The use of SUR, however, was justified through the results of Breusch-Pagan and likelihood ratio tests; the test statistics were 54.22 and 51.89, respectively. These test statistics had associated p-values of less than 0.0001. The R^2 for the system was 0.6442.

The results reported for the yield models in Tables 5.2 and 5.3 utilized the Kelliher weather station data. The choice of which weather data series to use (Wynyard or Kelliher) was decided through the use of a J-test, a non-nested model selection procedure, which indicated that the models utilizing the Kelliher weather station data were more appropriate (Griffiths et al., 1993)[35]. Autocorrelation was present in the oilseed yield equations, but was ignored. Autocorrelation was not unexpected given that the models did not include all possible explanatory variables that impact yield and for which data were not readily available. Existence of autocorrelation does not impact estimates of the coefficients, though it may affect the efficiency with which they were estimated possibly impacting their significance.

Table 5.2 – SUR crop yield model estimation results

Variable	Canola	Barley	Flax	Wheat
	Estimated Coefficient	Estimated Coefficient	Estimated Coefficient	Estimated Coefficient
GS/GDD	8.7401** (3.7621)	22.8300*** (5.4310)	8.5425*** (2.7984)	18.0630*** (3.4941)
$(GS/GDD)^2$	-21.2970** (-2.0917)	-47.4440*** (14.699)	-17.7670** (7.5739)	-42.9690*** (9.4567)
Constant	0.3574 (1.0997)	-0.1010 (0.4692)	0.1561 (0.2418)	0.1329 (0.3012)
Std. Error	0.2554	0.3687	0.1900	0.2372
R^2	0.1572	0.5488	0.3899	0.5040

Notes: * Represents significance at the 10% level, ** at the 5% level and * at the 1% level. Standard errors are in brackets.**

Table 5.3 – Correlations among errors of the estimated crop yield equations

	ε^C	ε^B	ε^F	ε^W
ε^C	1.0000			
ε^B	0.3459	1.0000		
ε^F	0.4553	0.6564	1.0000	
ε^W	0.4746	0.6377	0.3992	1.0000

Note: C, B, F and W represent canola, barley, flax and wheat, respectively.

5.2.1.2.2 Incorporating Crop Yield Models into the Simulation

The draws from the weather model for the *GS* and *GDD* variables served as the inputs for the water demand to water use ratio. The other component of the crop yield models were the error terms. Errors for each crop were drawn from standard normal distributions. Given the yield model assumed that the errors were correlated, each error also had to be adjusted according to the correlations between the crop yield equations and then scaled according to their respective standard deviations. The correlations between crop yield equations were calculated using the variance-covariance matrix from the SUR estimation.

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[35] J-test results are shown in Appendix H.

The error correlations were then calculated according to Hull (1997) using the following structure:

$$\varepsilon_m = \sum_{k=1}^{k=m} \alpha_{mk} x_k$$

subject to:

$$\sum_k \alpha_{mk}^2 = 1$$

$$\sum_k \alpha_{mk}\alpha_{jk} = \rho_{m,j}, \tag{5.3}$$

where ε_m was the corrected error for crop m, x_k was the initial standard normal error draw scaled according to the respective standard deviation of the crop, and $\rho_{m,j}$ was the correlation between the errors for crops m and j. The α_{mk} terms were estimated using the two constraints given. Since the crop rotation of the model farm had as many as four crops, four correlated error equations were needed. Solving for each of the α_{mk} terms resulted in the following equations:

$$\varepsilon_W = x_W \tag{5.4}$$

$$\varepsilon_C = \rho_{W,C} x_W + \left(\sqrt{1-\rho_{W,C}^2}\right) x_C \tag{5.5}$$

$$\varepsilon_B = \rho_{W,B} x_W + \left(\frac{\rho_{C,B} - \rho_{W,C}\rho_{W,B}}{\sqrt{1-\rho_{W,C}^2}}\right) x_C + \left[\sqrt{1-\rho_{W,B}^2 - \left(\frac{\rho_{C,B} - \rho_{W,C}\rho_{W,B}}{\sqrt{1-\rho_{W,C}^2}}\right)^2}\,\right] x_B \tag{5.6}$$

$$\begin{aligned}\varepsilon_F = {} & \rho_{W,F} x_W + \left(\frac{\rho_{C,F} - \rho_{W,C}\rho_{W,F}}{\sqrt{1-\rho_{W,C}^2}}\right) x_C + \left[\frac{\rho_{B,F} - \rho_{W,B}\rho_{W,F} - \left(\frac{\rho_{C,B} - \rho_{W,C}\rho_{W,B}}{\sqrt{1-\rho_{W,C}^2}}\right)\left(\frac{\rho_{C,F} - \rho_{W,C}\rho_{W,F}}{\sqrt{1-\rho_{W,C}^2}}\right)}{\sqrt{1-\rho_{W,B}^2 - \left(\frac{\rho_{C,B} - \rho_{W,C}\rho_{W,B}}{\sqrt{1-\rho_{W,C}^2}}\right)^2}}\right] x_B \\ & + \left\{\sqrt{1-\rho_{W,F}^2 - \left(\frac{\rho_{C,F} - \rho_{W,C}\rho_{W,F}}{\sqrt{1-\rho_{W,C}^2}}\right)^2 - \left[\frac{\rho_{B,F} - \rho_{W,B}\rho_{W,F} - \left(\frac{\rho_{C,B} - \rho_{W,C}\rho_{W,B}}{\sqrt{1-\rho_{W,C}^2}}\right)\left(\frac{\rho_{C,F} - \rho_{W,C}\rho_{W,F}}{\sqrt{1-\rho_{W,C}^2}}\right)}{\sqrt{1-\rho_{W,B}^2 - \left(\frac{\rho_{C,B} - \rho_{W,C}\rho_{W,B}}{\sqrt{1-\rho_{W,C}^2}}\right)^2}}\right]^2}\,\right\} x_F\end{aligned} \tag{5.7}$$

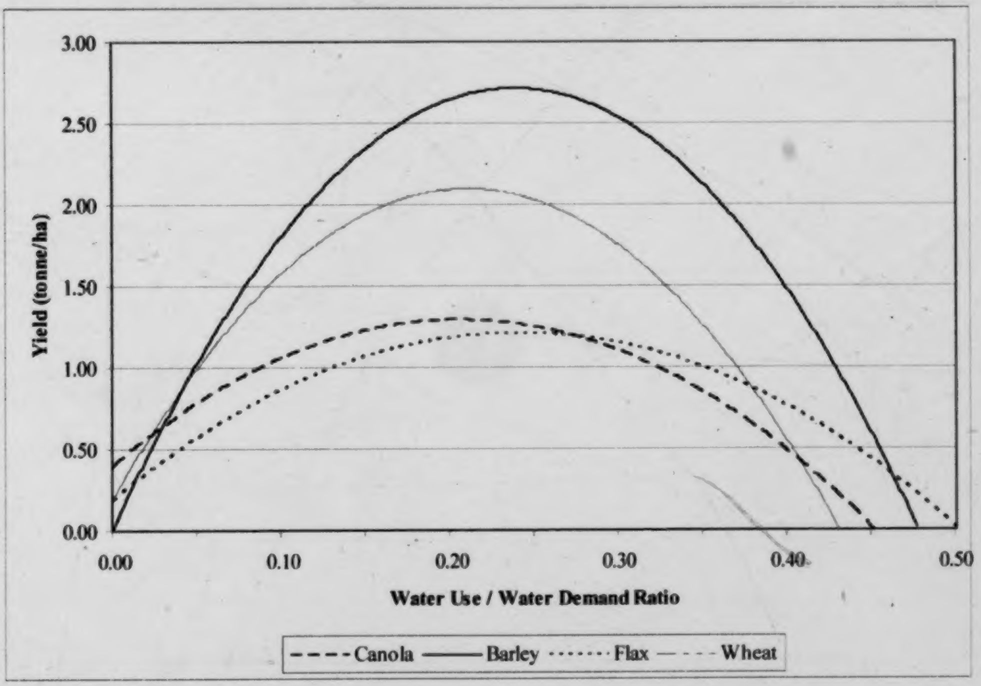
The *GS/GDD* ratio and the adjusted errors were then substituted into the yield regression equations to calculate yields for each crop. For the crop rotation with only two crops, only the first two error correlation equations were utilized.

5.2.1.2.3 Calibration and Validation of Crop Yield Models

Even with the bounds on the *GS* variable, some yield simulation results contained negative yields. Negative yields resulted from very low and very high *GS/GDD* ratios. This problem was corrected by simply setting the minimum yield to zero for all crops.

The next problem was that the means of the simulation model for yields were not equal to the RM average for each of the crops. This problem was addressed by changing the constants in each equation, so that test simulations returned mean yields that approximated the RM averages. Figure 5.3 provides a graph of the calibrated yield equations. Yield curves for each crop yield equation behaved as expected; barley yields per hectare were the highest, followed by wheat. Canola and flax had similar yields which were much less than that of the two cereal crops. Figure 5.3 also reflects the findings of Rigaux and Singh (1997), who found that wheat and barley were more sensitive to moisture than oilseed crops, particularly flax.

Figure 5.3 – Graph of the calibrated yield equations



Variances and covariances of the crop yields also had to be adjusted to reflect differences in risk at the farm level versus the RM level. Using aggregate data, such as RM data, may introduce an aggregation bias into the model by underestimating the farm level variances in yields and lead to erroneous research conclusions (Fulton et al., 1988; Rudstrom et al., 2002). Existing literature provided little guidance as to how to perform such adjustments, although there was agreement that aggregated yields would be less variable than farm level yields (Fulton et al., 1988).

In the present study, variances were adjusted upward in an ad-hoc manner so that the maximum yield would be similar to those provided by the Saskatchewan Crop Insurance Corporation (SCIC) for the years 1997-2002 (Hulston, 2004). Maximums for the RM were 4.68 tonnes/ha for barley, 4.43 for wheat , 2.52 for canola, and 1.94 for flax (Hulston, 2004). One problem that emerged was that the wheat variance had to be adjusted considerably in order for the model to reach a maximum simulated wheat yield of 4.43 tonnes/ha. This resulted in wheat yields of 0 tonnes/ha about 1% of the time. The model produced yields of 0 tonnes/ha for the other crops about 0.5% of the time. Based on this, the wheat variance was reduced so that yields of 0 tonnes/ha would occur at approximately the same rate as the other crops. After the adjustment, wheat yield would no longer reach the maximum, although the final calibration simulation did contain a wheat yield of 4.12. Covariances were adjusted so that the correlations remained similar to initial values.

Once the variances were adjusted upward to appropriate levels, the adjusted variances were compared to an adjustment factor estimated by Marra and Schurle (1994) for Kansas wheat yields at the county versus the farm level. Their analysis concluded that the standard deviation of wheat yield would increase by 0.1% for every 1% difference between average farm acreage and county acreage. This adjustment factor was used to determine appropriate standard deviations in yield at the farm level for the crops used within this analysis. Table 5.4 shows the comparison between the estimated standard deviation using the Marra-Schurle factor and the estimate using ad-hoc adjustments in order to obtain SCIC data maximum yields.

Table 5.4 – Standard deviation adjustments comparison by crop

	Standard Deviation of Yield (tonne/ha)			
	Canola	Barley	Flax	Wheat
Marra-Schurle Factor	0.31	0.61	0.27	0.38
Simulation Model	0.37	0.71	0.27	0.58
% Difference	20%	17%	-1%	54%

Even though the Marra-Schurle study only analyzed comparisons of risk for wheat, the adjusted standard deviations for the other crops used in this analysis compared quite favourably with the adjustments based on the Marra-Schurle factor. However, the standard deviation for wheat was considerably higher than the estimated standard deviation using the Marra-Schurle factor. The size of the variance adjustment was not surprising since the difference between the observed mean wheat yield and the maximum wheat yield provided by SCIC was the greatest among the crops. Other literature was consulted due to the large difference between the two values. Debrah and Hall (1989) found that farm level wheat yields in Kentucky had standard deviations 2.71 times higher than that of county level data. Also, Rudstrom et al. (2002) found the standard deviation in field level wheat yield to be as much as 2.24 times greater than municipality variances in Manitoba. The adjustment made in the simulation model to the wheat variance represented an increase in the standard deviation of 1.70, which was below the values observed in both the Debrah and Hall (1989) and the Rudstrom et al. (2002) studies.

The 90% confidence intervals for the calibrated yield models and SCIC data are shown in Table 5.5 (Hulston, 2004). Average yields in the RM from SAFRR data are also shown (SAFRR, 2004c). The figures for the simulation model compared favorably with the RM mean yields for 1967-2001 and confidence interval data acquired from SCIC for the years 1997-2002 (Hulston, 2004). It was expected that the confidence interval for the model results would be narrower than that of the SCIC data because the model's estimates were based on a longer time period.

Table 5.5 – Means and confidence intervals for crop yields for the simulation model, SCIC data, and SAFRR data (Hulston, 2004; SAFRR, 2004c)

Simulation Model				
	Crop Yield (tonne/ha)			
	Canola	Barley	Flax	Wheat
Upper 90% CI[a]	1.75	3.41	1.47	2.73
Mean	1.17	2.34	1.07	1.85
Lower 90% CI	0.53	1.04	0.58	0.81
SCIC and SAFRR Data				
	Crop Yield (tonne/ha)			
	Canola	Barley	Flax	Wheat
SCIC Upper 90% CI	2.08	4.00	1.83	3.11
SCIC Mean	1.26	2.36	1.07	1.91
SCIC Lower 90% CI	0.45	0.73	0.31	0.70
SAFRR Mean	1.17	2.34	1.07	1.84

Note: [a] CI represents confidence interval.

No literature was found on adjustments to covariances between crops, but summaries of correlations between crops in the various risk areas in Alberta and on individual farms within these risk areas were provided by Brian Radke (2004) for 13 years of crop insurance data. Risk areas contain several rural municipalities. These summaries indicated that risk areas had higher correlations than individual farms. The crop yield correlations for Emerald were left unchanged since they were similar to the correlations of the individual farms in the various risk areas in Alberta.

5.2.1.3 Commodity Price Models

5.2.1.3.1 Estimation of Commodity Price Models

Commodity price data for Saskatchewan were taken from the Agriculture Statistics Handbook produced by SAFRR (SAFRR, 2004d). The price series used was from 1960-2002 for all crops grown on the model farm. Prior to model development, the data were deflated using the latest annual CPI and then converted to natural logarithms.

The data were tested for stationarity before modeling was undertaken. Dickey-Fuller test results in Table 5.6 suggest that the price series was non-stationary. Both tests, without a trend and with a trend, yielded test statistics that were less than the critical values in absolute terms at 10% significance levels for all price series. Therefore, the null hypothesis that the data were non-stationary was not rejected. These results were supported by inspection of the autocorrelation functions of each of the price series. Slow decay of the functions once again indicated the presence of non-stationarity[36].

Table 5.6 – Dickey-Fuller test results for non-stationarity within commodity price series

Crop	Without Trend	With Trend
Canola	-1.1785	-2.1953
Barley	-1.8741	-2.8541
Flax	-1.2384	-2.3250
Wheat	-1.2661	-2.3582
Critical Value (10%)	-2.57	-3.13

Due to the presence of non-stationarity in the price series, first-order differencing was performed to provide a stationary series. Dickey-Fuller tests were then used again to determine whether the price series with first-order differencing was stationary. The results are presented in Table 5.7 and they indicate that first-order differencing resulted in stationary data series since all calculated test statistics were greater than the critical values in absolute terms.

Table 5.7 – Dickey-Fuller test results for non-stationarity within commodity price series with first-order differencing

Crop	Without Trend	With Trend
Canola	-4.0805	-4.0082
Barley	-4.1865	-4.1058
Flax	-3.9449	-3.8851
Wheat	-4.3322	-4.2589
Critical Value (5%)	-2.86	-3.41

A non-stationary price model was then estimated using the following equation:

$$P_t^m = \alpha_0 + P_{t-1}^m + \varepsilon_t^m, \tag{5.8}$$

where P_t^m was the price for crop *m*, P_{t-1}^m was the price for crop *m* in the previous period, and α_0 was a constant. The constant can be manipulated to add a trend to the series; a positive constant would yield an upward trend, while a negative constant would yield a downward trend. The α_0 term was assumed to be zero, which does not add a trend to the price series since it would be difficult to determine a trend in commodity prices over a 20-year period. The error term was estimated using the variance of the first-order differenced price series. The non-stationary price equations for each crop were estimated using SUR. Given that there were no parameters to estimate, only the correlations between equations were needed for the non-stationary price model (Table 5.8).

Table 5.8 – Correlations among errors of the estimated non-stationary commodity price equations

	ε^F	ε^B	ε^C	ε^W
ε^F	1.0000			
ε^B	0.7067	1.0000		
ε^C	0.7099	0.4957	1.0000	
ε^W	0.7739	0.8372	0.6061	1.0000

Note: C, B, F and W represent canola, barley, flax and wheat, respectively.

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[36] Autocorrelation functions of each price series are available in Appendix I.

A non-stationary process can produce a wide confidence interval for forecasts over a long period of time; therefore, a stationary price model was developed for comparison purposes. To determine the number of lagged price variables to include in each crop yield equation, the Akaike Information Criterion (AIC) and Schwartz Criterion (SC) were used. Equations for one through five lagged price variables were estimated for each crop and the minimum AIC and SC numbers were compared to determine the most appropriate number of lags to use. The AIC and SC values obtained from ordinary least squares (OLS) regressions are included in Table 5.9.

Table 5.9 – AIC and SC values for lagged commodity price equations

	AIC				SC			
Lags	Wheat	Canola	Barley	Flax	Wheat	Canola	Barley	Flax
1	0.0574	0.0412	0.0592	0.0824	0.0627	0.0450	0.0646	0.0899
2	0.0566	0.0407	0.0594	0.0769	0.0645	0.0464	0.0676	0.0876
3	0.0536	0.0387	0.0604	0.0669	0.0638	0.0461	0.0718	0.0796
4	0.0566	0.0406	0.0637	0.0694	0.0703	0.0505	0.0792	0.0862
5	0.0564	0.0421	0.0649	0.0732	0.0733	0.0547	0.0842	0.0951

From Table 5.9, the most appropriate models according to the AIC were equations with three lags for wheat, canola and flax and one lag for barley. The minimum SC values were for equations with one lag for wheat, canola and barley and three lags for flax. The number of lags selected were those determined through the AIC since for both wheat and canola, the third lag also provided a reduction in the SC value, though it was not the minimum. Thus, the stationary price model was estimated as follows:

$$\begin{aligned}
P_t^C &= \gamma_0 + \gamma_1 P_{t-1}^C + \gamma_2 P_{t-2}^C + \gamma_3 P_{t-3}^C + \varepsilon_t^C \\
P_t^B &= \gamma_0 + \gamma_1 P_{t-1}^B + \varepsilon_t^B \\
P_t^F &= \gamma_0 + \gamma_1 P_{t-1}^F + \gamma_2 P_{t-2}^F + \gamma_3 P_{t-3}^F + \varepsilon_t^F \\
P_t^W &= \gamma_0 + \gamma_1 P_{t-1}^W + \gamma_2 P_{t-2}^W + \gamma_3 P_{t-3}^W + \varepsilon_t^W \, , \qquad (5.9)
\end{aligned}$$

where P_t was the current price, P_{t-1} was last year's price, P_{t-n} was the price lagged n times, γ_0 was a constant, and γ_1 through γ_n were coefficients on the lagged price terms.

The stationary price equations were also estimated using SUR. Here, since the explanatory variables were different for each of the price equations, the use of SUR may provide more robust estimates of the coefficients as well as better estimations of the error term. The results are shown in Tables 5.10 and 5.11. The system R^2 is 0.7870. The Breusch-Pagan and likelihood ratio test statistics were 97.11 and 127.79, respectively, confirming the use of SUR as an appropriate estimator. Both test statistics correspond to p-values less than 0.0001. All coefficients were significant at the 1% level with the exception of the 3rd lag in the canola price equation.

5.2.1.3.2 Incorporating Commodity Price Models into the Simulation

As in the crop yield models, the errors of the estimates for commodity prices were assumed to be correlated. The correlations between the first-order differences of the price series were used as correlation coefficients for the non-stationary price model. The SUR price model provided a variance-covariance matrix from which the correlations between

Table 5.10 – SUR stationary commodity price model estimation results

Variable	Canola	Barley	Flax	Wheat
	Estimated Coefficient	Estimated Coefficient	Estimated Coefficient	Estimated Coefficient
Lag 1	0.8783***	0.5443***	0.8128***	0.6742***
	(0.1133)	(0.0793)	(0.0919)	(0.0862)
Lag 2	-0.4640***		-0.4447***	-0.2700***
	(0.1581)		(0.1149)	(0.0927)
Lag 3	0.2739**		0.2572***	0.2168***
	(0.1141)		(0.0831)	(0.0667)
Constant	1.9336***	2.3948***	2.3052***	2.0972***
	(0.5033)	(0.4215)	(0.4656)	(0.4196)
Std. Error	0.1948	0.2527	0.2681	0.2407
R^2	0.7366	0.6036	0.7153	0.6843

Notes: * Represents significance at the 10% level, ** at the 5% level and * at the 1% level. Standard errors are in brackets.**

Table 5.11 – SUR correlations between stationary commodity price equations

	ε^F	ε^B	ε^C	ε^W
ε^F	1.0000			
ε^B	0.8243	1.0000		
ε^C	0.8184	0.6616	1.0000	
ε^W	0.8503	0.9246	0.6701	1.0000

Note: C, B, F and W represent canola, barley, flax and wheat, respectively.

commodity prices were calculated for the stationary model. The error specifications for the price models were identical to those utilized in the crop yield models (section 5.2.1.2.2). However, the different correlations between variables resulted in different values for the α_{mk} terms. Once again, random draws from standard normal distributions were used for the error terms for the price of each crop. Each error was then corrected for the correlation between prices and scaled according to their respective standard deviation. The same error draw was, however, used to calculate the stationary and non-stationary price for each crop. This allowed comparison of results between the two price models.

5.2.1.3.3 Calibration and Validation of Commodity Price Models

In the simulation analysis, the commodity prices were assumed to exhibit no trend over the 20-year period. Since the distributions for the price models were lognormal, the mean of the non-stationary model drifted upward over time. The drift in the non-stationary price model was removed by subtracting a factor of $\sigma^2/2$ from the constant (Hull, 1997). The stationary model also exhibited a slight upward drift from converting the logarithm of prices back to $/tonne. This occurred because the logarithm of prices was a normal distribution and therefore, the distribution for $/tonne was skewed to the right. It was the prices in right tail of the distribution that caused this slight upward drift in the mean of the $/tonne distribution. This problem was considered sufficiently significant to warrant correction as higher priced commodities such as flax had average prices in year 20 of the simulation that were as much as $20/tonne or more higher than the starting price. Correcting the problem was accomplished by simply subtracting the difference between the starting price and the average of the mean simulation prices for years 1 through 20 from the price determined by the stationary regression equation. This was an ad-hoc adjustment since no literature was found providing insight into solutions for this problem.

Although the data suggest that commodity prices were non-stationary, prices for commodities reached levels as high as $20,000/tonne and as low as $1.00/tonne utilizing the non-stationary price equations. The extremely wide and infeasible range in prices that resulted over the 20-year period precluded its use for this simulation. Dixit and Pindyck (1994) offer support to this decision; they stated that the price of commodities should, over the long-run, revert back towards the marginal cost of production. It should also be noted that the price models estimated were based on 43 data points and Dixit and Pindyck (1994) argued that distinguishing between a non-stationary and stationary process is difficult with only about 30 years of data. Verbeek (2004) also noted that the Dickey-Fuller test has low power. The null hypothesis is that a unit root exists and that even though one is unable to reject the null hypothesis, it does not necessarily mean that it is true; there may just be insufficient evidence in the data to reject it (Verbeek, 2004). Also, none of the studies that used simulation to analyze wetland drainage checked for the existence of non-stationarity in prices[37]. The researchers simply used distributions based on historical prices. As a result, the stationary commodity price models were used in the analysis.

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[37] These studies are summarized in section 2.3.3.

5.2.1.4 Time Available to Conduct Drainage

5.2.1.4.1 Estimation of Time Available to Conduct Drainage

The time available for drainage in the fall was estimated by determining the number of workdays between the date when crops mature and freeze-up. Time to conduct harvest activities, drainage maintenance and summerfallow activities were then subtracted from available workdays. The remaining days were those that could be devoted to drainage activities. Existing research, most of which was conducted in the 1960's and 1970's, used soil moisture to estimate whether a farm operator could conduct field work on a given day. Two Canadian studies that were specifically used for this research were by Rutledge and McHardy (1968) and Baier (1973).

Rutledge and McHardy (1968) estimated probabilities of workdays and non-workdays for tillage operations in medium to heavy and sandy soil types in various Alberta regions using a soil moisture model. This paper was chosen because the research approach was consistent with the methods used in this simulation. Workday/non-workday probabilities were based on weather, which was similar to the method used for calculating yields in the present study. However, the probabilities for workdays/non-workdays were implicitly based on weather and it was not necessary to explicitly model weather to use the Rutledge and McHardy (1968) method of determining whether or not a given day was a workday/non-workday.

Due to similarity in weather, medium to heavy soil workday/non-workday probability estimates for Edmonton and Vermillion were chosen as the most appropriate for the present study from a list that also included Medicine Hat, Lethbridge, Calgary, Beaverlodge and Fairview. Persistence of weather events was also accounted for and separate probabilities were listed for workdays/non-workdays when the previous day was also a workday/non-workday. This conditional probability could be used to calculate probabilities for consecutive workdays/non-workdays. The probability of five consecutive workdays would be calculated as follows, from the 2000 version of the American Society of Agricultural Engineers (ASAE) Standards Handbook (ASAE, 2000):

$$P(5W) = P(W) * P(W \mid W)^4, \qquad (5.10)$$

where P(5W) is the probability of five consecutive workdays, P(W) is the probability that a particular day is a workday and P(W|W) is the probability that a day is a workday conditional on the previous day being a workday. As the number of consecutive days is increased, the probability of having that many workdays in succession decreased. Research findings from Rutledge and McHardy (1968) used in the development of the time component of the present study are shown in Table 5.12.

The second paper, by Baier (1973), estimated field workdays for several Canadian locations, again using a soil moisture model. This paper was chosen for use in determining the time component of the project since workday estimates were calculated by month and crop growth stage (Tables 5.13 and 5.14). The values in Tables 5.13 and 5.14 were invaluable for determining an appropriate fall period for the study area. The final stage, ripe to freeze-up, was used to estimate workdays within the harvest season. Because of similarities in weather and soil type, the Brandon estimates were chosen as the most appropriate location to base the harvest simulation on from a list that also included Normandin, Quebec, Charlottetown, Prince Edward Island, Agassiz, British

Table 5.12 – Workday and non-workday probability findings from Rutledge and McHardy (1968)

Workday Probabilities						
	August		September		October	
City	Unconditional	Conditional[a]	Unconditional	Conditional	Unconditional	Conditional
Edmonton	0.68	0.80	0.58	0.88	0.41	0.89
Vermillion	0.70	0.82	0.54	0.89	0.41	0.91
Non-workday Probabilities						
	August		September		October	
City	Unconditional	Conditional	Unconditional	Conditional	Unconditional	Conditional
Edmonton	0.32	0.62	0.42	0.84	0.59	0.91
Vermillion	0.30	0.62	0.46	0.86	0.59	0.92

Note: [a] Conditional probabilities are based on whether the previous day was a workday/non-workday.

Table 5.13 – Average monthly workdays findings from Baier (1973)

City	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Total
Brandon	9.8	23.7	22.2	25.7	25.1	23.4	19.6	4.8	154.3

Table 5.14 – Findings for average length of period and number of workdays in each period from Baier (1973)

Average length of period							
City	Assumed Planting Date	Planting to Emergence	Emergence to Jointing	Jointing to Heading	Heading to Soft Dough	Soft Dough to Ripe	Ripe to Freeze-up
Brandon	May 5	10	24	24	20	11	91
Average number of workdays in each period							
City	Assumed Planting Date	Planting to Emergence	Emergence to Jointing	Jointing to Heading	Heading to Soft Dough	Soft Dough to Ripe	Ripe to Freeze-up
Brandon	May 5	7.8	18.4	18.8	17.1	10.2	65.3

Columbia, Ottawa, Ontario, Fort Simpson, Northwest Territories, Fort Vermillion, Alberta, Harrow, Ontario, Lethbridge, Alberta, and Swift Current, Saskatchewan.

The ripe to freeze-up period for the study area was determined using the weather records from the two stations at Kelliher and Wynyard (Boychuk, 2004). These data were compared to those from the cities that were used within the Rutledge and McHardy (1968) and Baier (1973) studies. Mean temperature and precipitation values from 1961-1990 from www.theweathernetwork.ca for the months of August, September, October, and November from Edmonton and Brandon were compared to values from the study area to determine whether changes to the model were necessary (The Weather Network, 2005). These values are listed in Table 5.15. The comparison suggested that Brandon has higher rainfall and temperature than the RM of Emerald. Brandon is also further south than the study area. Therefore, it was assumed that the RM of Emerald would have a shorter ripe to freeze-up period than Brandon.

Table 5.15 – Mean temperature and precipitation values during August, September, October, and November for selected cities (1961-1990)

	Precip (mm)	Temp (^{O}C)
Brandon	157	7.32
Edmonton	152	6.31
Kelliher	134	6.23
Wynyard[a]	130	6.46

Notes: [a] 1965-1990. Vermillion data were not available.

Workdays in the four months of the ripe to freeze-up period, August, September, October and November, were modeled using the workday probability schedules from Rutledge and McHardy (1968). The probability that August 1st was a workday was calculated using the unconditional probability from Edmonton as a starting point since both Edmonton and Vermillion had similar probabilities. A uniform distribution with bounds of zero and one from @Risk© was used to determine whether or not August 1st was a workday. If the stochastic draw from the uniform distribution was less than the workday probability, then August 1st was listed as a workday within the simulation.

The determination of workdays and non-workdays for each subsequent day in the simulation was then based on whether or not the previous day(s) were workdays or non-workdays. If the previous day was a workday, then the model calculated whether or not the current day was a workday based on the conditional probability for Edmonton for the month in which the day lies. As the number of consecutive workdays increased, the probability that the current day was a workday decreased as previously described. Again, if the random draw from the uniform distribution was less than the probability that the day in question was a workday, then the day was listed as a workday. Non-workdays were determined in the same manner, except that the conditional probabilities for non-workdays were used instead. The final day of the harvest simulation was set as November 12th, as it was presumed that it would provide an estimate for average workdays in November similar to the value given in Baier (1973) for Brandon. Workday probabilities for November were extrapolated from the data in Rutledge and McHardy (1968) and were similar to the research findings from October in Table 5.12.

5.2.1.4.2 Incorporating Time Available to Conduct Drainage into the Simulation

The time available to conduct drainage was calculated as a residual after other field activities were completed, the first of which were harvesting operations. The ripening of the crop indicated that harvesting activities could begin. Six possible crop maturity dates were used within the simulation: August 7th, August 14th, August 21st, August 28th, September 4th, and September 11th. Allowing for different crop maturity dates within the model increased the variability in the harvest season and added realism to the simulation. The crop maturity date was determined by the *GDD* variable, lower *GDD* values for the growing season resulted in later crop maturity dates and higher values resulted in earlier crop maturity dates. Crop maturity dates for crops seeded on May 15th are shown in Table 5.16. They were determined using data from www.wintercereals.ca, a DUC sponsored website that calculated crop maturity dates based on *GDD* values (DUC, 2005). Each of the figures listed is the probability that the crop listed will reach maturity by the date listed. For example, the probability that wheat seeded on May 15th will be ripe on August 25th is 0.26.

Table 5.16 – Probability of crop maturity for crops seeded on May 15th by calendar date

	Crop Maturity Date									
	5-Aug	10-Aug	15-Aug	20-Aug	25-Aug	30-Aug	4-Sep	9-Sep	14-Sep	19-Sep
Canola	0.04	0.04	0.28	0.60	0.79	0.83	0.87	0.87	0.96	0.98
Flax	0.00	0.02	0.02	0.04	0.13	0.30	0.55	0.64	0.72	0.77
Wheat	0.00	0.02	0.04	0.04	0.26	0.47	0.57	0.72	0.77	0.79
Barley	0.64	0.83	0.83	0.96	1.00	1.00	1.00	1.00	1.00	1.00

For the harvest simulation it was assumed that once farm operators began harvesting, they would be able to harvest on all days estimated as workdays (i.e. farm operators would always have crops ready to harvest once harvest began). The potential first day of harvesting operations was determined by calculating averages of crop maturity dates for the crops included in the different crop rotations. These averages are listed in the Table 5.17. Separate averages were used for each of the different crop rotations within the model since each crop had a different maturity date. Only two different calculations were required since the 4-year and 5-year crop rotations were comprised of the same crops. The only difference was that one included summerfallow and the other did not. These probabilities show that including barley in a rotation allowed a farm operator to begin harvesting earlier as barley was the earliest maturing crop among those included in the rotations. Midpoints were then taken from Table 5.17 and the *GDD* values that correspond to that probability level from the *GDD* distribution were used as thresholds for the crop maturity date. Table 5.18 indicates these *GDD* threshold values for crop maturity dates by crop rotation.

Table 5.17 Average probability of physiological crop maturity date by crop rotation

	Crop Maturity Date					
Crops Included in Rotation	7-Aug	14-Aug	21-Aug	28-Aug	4-Sep	11-Sep
Canola-Barley-Flax-Wheat	0.20	0.29	0.41	0.60	0.75	0.84
Canola-Wheat	0.03	0.16	0.32	0.59	0.72	0.83

Table 5.18 – *GDD* values used for determining physiological crop maturity date

	Crops Included in Rotation	
Crop Maturity Date	Canola-Barley-Flax-Wheat	Canola-Wheat
7-Aug	≥ 1077.00	≥ 1,138.70
14-Aug	<1077.00, ≥ 1,052.70	< 1,138.70, ≥ 1,079.70
21-Aug	< 1,052.70, ≥ 1,021.30	< 1,079.70, ≥ 1,031.40
28-Aug	< 1,021.30, ≥ 985.30	< 1,031.40, ≥ 989.80
4-Sep	< 985.30, ≥ 954.00	< 989.80, ≥ 957.00
11-Sep	< 954.00	< 957.00

Harvest activities were then scheduled according to the workdays estimated. The farm operator began swathing on either the crop maturity date or the first available workday after the crop maturity date. The farm operator swathed until the number of hours spent swathing exceeded the value for the time to swath all cropped quarter sections on the farm. Swathing times for each quarter section were taken from the data for each quarter section operated by the farm. It was assumed that a farm operator worked 10 hours each workday during the harvest season. Therefore, if the swathing time for a particular farm was 96 hours, a farm operator would require 10 workdays to complete swathing operations. Combining began on the next workday after swathing was completed and continued until the hours spent combining exceeded the total hours necessary to combine all crops on the farm, which, once again, were listed for each quarter section.

Once harvest was complete, the remaining time before freeze-up could be allocated to other activities such as drainage. However, after harvest was complete, it was assumed that the farm operator only spent an average of 6 hr each workday performing field operations. The number of workdays remaining for other operations was determined by subtracting the number of days required to complete harvest operations from the total number of workdays in the fall season. Time spent maintaining existing drainage ditches, fall spraying of problem weeds on cropped lands and time spent performing summerfallow operations (if summerfallow was included in the rotation) were also subtracted from the total number of workdays in the fall season. All farms were assumed to spray their summerfallow prior to freeze-up since weed control is one reason for utilizing summerfallow in a rotation. The remaining days after subtracting times for these activities were those that could be allocated to construction of new drainage ditches and rehabilitation of drained lands.

5.2.1.4.3 Calibration and Validation of Time Available to Conduct Drainage

Calibration was performed using average workday values from Table 5.13 for the months of August, September, October and November, which were, respectively, 25.1, 23.4, 19.6 and 4.8 days. Since the ripe to freeze-up period for the RM of Emerald was assumed to be shorter than for Brandon, calibration was performed by altering the workday/non-workday probabilities so that monthly workday estimates were slightly less than those indicated above. The resulting workday probabilities used in the simulation are listed in Table 5.19. Calibration resulted in an average ripe to freeze-up period of about 80 days and on average, 52 of those days were workdays. These figures were lower than the estimates from Baier (1973) of 65 workdays in a 91 day ripe to freeze-up period and seemed plausible for the study area.

Table 5.19 – Workday and non-workday probabilities used in the simulation versus Rutledge and McHardy (1968) results for Edmonton

Workday Probabilities

	August		September		October	
City	Unconditional	Conditional[a]	Unconditional	Conditional	Unconditional	Conditional
Edmonton	0.68	0.80	0.58	0.88	0.41	0.89
Simulation	0.80	0.95	N/A	0.93	N/A	0.88

Non-workday Probabilities

	August		September		October	
City	Unconditional	Conditional	Unconditional	Conditional	Unconditional	Conditional
Edmonton	0.32	0.62	0.42	0.84	0.59	0.91
Simulation	0.20	0.38	N/A	0.50	N/A	0.70

Notes: [a] Conditional probabilities are based on whether the previous day was a workday/non-workday. Unconditional probabilities are not needed within the model for any other month but August because each day in the simulation other than August 1st is based on results for previous days. The unconditional workday and non-workday probabilities used for November were 0.76 and 0.90, respectively.

The probabilities, especially non-workday probabilities, used in the simulation differed significantly from the research findings of Rutledge and McHardy (1968). However, the purpose of their research was to estimate suitable days for tillage operations and did not provide any estimates such as monthly averages for workdays/non-workdays that would have been useful for calibration. Again, the Rutledge and McHardy (1968) paper was chosen for use in developing this portion of the model because of the method used to determine workdays/non-workdays; it was expected that large changes to the workday/non-workday probabilities would be necessary. The Baier (1973) study discussed field operations other than tillage and fall workdays estimated by Baier (1973) were useful for calibration and validation.

Harvest completion dates from the simulation were then compared to combining progress reports compiled by SAFRR for the region including Emerald (Bedard, 2004). A representative farm that operated about the same amount of cropland as the largest farm in the RM of Emerald was used in calibration simulations for comparison purposes, as it was expected that larger farms would have later completion dates for harvesting operations. According to SAFRR reports for the years 1996-2004, on average, combining in this area was completed by approximately October 22nd, while the representative farm completed harvest by October 24th 90% of the time. Although these figures were not directly comparable, they provided evidence that this component of the simulation seemed to represent what occurs in reality.

5.2.2 Economic Relationships

The simulation model was calculated as a cash flow model in order to be consistent with NPV analysis. Revenues and costs for a farm operation were used to determine cash flow and are discussed in this section. The steps used in calculation of these components are described in detail. The majority of revenues for a grain operation are derived from the sale of harvested crops. Since commodity prices and crop yields were estimated as stochastic variables, revenues exhibited a high degree of variability from year to year. Costs included in the analysis were input costs and machinery operation expenses and based on current data sources.

5.2.2.1 Revenues

Revenues were simulated using estimates for yields and prices. The yield simulation included random draws from the logistic distributions for precipitation and growing degree days. The error component utilized in the yield equations estimated impacts from sources outside of the estimated weather components (i.e. weed and disease problems, severe weather events, etc.). This introduced some variability into the yields, which could result in canola yield, for example, being greater than wheat yield in a given year. Crop yields for each quarter section differed because of differences in cropped basin and wetland areas. For cropped basins that were not drained, the yield was equal to 0 tonnes/ha whenever the random draw for precipitation was greater than a threshold level, lowering the average yield for the quarter section. In the simulation yields in cropped basins were 0 tonnes/ha 4 out of 10 years; therefore when the random draw for precipitation for a particular year was greater than the 60th percentile, yields in cropped basins were 0 tonnes/ha. When cropped basins were drained, they produced crops every year and this resulted in differences in yields on identical quarter sections between when the farm did not conduct drainage and when the farm expanded its cultivated land base through drainage.

In terms of commodity prices, as described in section 5.2.1.3.3, only the stationary models were used in the analysis. The starting prices for the simulation were the 10-year average prices over the period 1993 to 2002 and these prices were also assumed to be the mean of the distribution in each year of the simulation. The prices for each year in the 20-year simulation period were estimated by the stationary process. Farm revenue was then derived simply multiplying the price of each crop by the yield and the hectares of each crop in each quarter section and then summing these values across quarter sections.

5.2.2.2 Input Costs

Input costs were taken from enterprise budgets for 2003 obtained from SAFRR (Novak, 2004). Costs for various crops grown in Saskatchewan were listed by soil zone and tillage practice, including conventional seeded, direct seeded and fallow seeded crops. Production costs for the black soil zone were used in this analysis since the study area lies within this soil zone. Direct seeded costs were mainly used since the farm was assumed to utilize no-till farming practices. Fallow seeded costs were also required because two of the rotations used in this analysis included seeding canola on summerfallow and input costs on summerfallow were lower than continuous cropping costs.

Input costs incorporated into the model included seed, pesticide, and fertilizer costs (Table 5.20). Seed and fertilizer costs were taken from the SAFRR enterprise budgets. Pesticide costs, however, were calculated as the total pesticide cost from the enterprise budgets plus custom spraying charges for application of fungicides (Novak, 2004). It was assumed that the farm operator applied all their own pesticides except for fungicides because they are often applied at later crop growth stages and need to be applied using a high-clearance sprayer. Farm operators generally do not own high-clearance sprayers unless they perform custom spraying for other farm operators in the area; therefore, this was a reasonable assumption. Fungicides were assumed to be applied according to SAFRR application rates (Novak, 2004). For example, it was assumed that 40% of wheat hectares were treated with fungicides each year.

Table 5.20 – Input costs by crop ($/ha)

	Crop					
Input	Canola[a]	Canola	Barley	Flax	Wheat	Fallow
Seed	50.26	50.26	18.63	19.89	26.87	0.00
Fertilizer	55.84	78.08	63.75	63.75	63.75	0.00
Pesticide	46.19	53.93	50.43	61.00	58.73	29.89
Total	152.29	182.27	132.81	144.64	149.36	29.89

Note: [a] Indicates crops planted on summerfallow.

5.2.2.3 Machinery Costs

Machinery operating expenses (fuel and machinery repair) for no-till cropping practices are shown in Table 5.21. These costs were taken from the SAFRR Farm Machinery Custom and Rental Rate Guide (SAFRR, 2004d) for the appropriate machinery implements as listed in Table 5.1[38]. Costs were deflated to 2003 dollars using the CPI for all goods for Canada (Statistics Canada, 2004). The non-harvest and summerfallow operation costs were listed for each quarter section, while swathing and combining operations needed to be calculated by multiplying the time to complete each operation in each quarter section by their respective machinery operating costs.

5.2.3 Farm Programs

Two farm "safety net" programs, the CAIS program and crop insurance, were included in the model as they can potentially alter the returns and risks of farming, and could influence the number of drainage projects conducted by a farm operator. The CAIS program is a federally funded program that offers protection to farm operators that experience negative deviations from their average level of returns. Crop insurance has been available to farm operators for decades and provides support in years of low yields or crop disasters. Analyses of farm programs and their impact on wetlands have been conducted by Kramer and Shabman (1993), Danielson (1989), McColloch and Wissman (1988), and Heimlich and Langner (1986) for the United States. Price and income supports, taxation policy, and the "Swampbuster" program were the main programs studied[39]. Summaries of these studies were provided in the section 2.3.2.

5.2.3.1 Crop Insurance

Crop insurance was included in the simulation since it appeared that the majority of hectares in the RM of Emerald are enrolled in the program. For example, 64% of spring wheat, 72% of barley, 72% of canola and 72% of flax were covered by crop insurance in 2001 (Hulston, 2005). Crop insurance provides compensation to farm operators in years of low yields. It was modeled using a crop insurance calculator provided by SCIC incorporating the costing parameters for 2003 (Hulston, 2005). The average coverage level of 70% used within the RM of Emerald was the only coverage level modeled within the simulation. This level was also chosen because benefits associated with crop insurance at the 70% coverage level affect payments received through the CAIS program.

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[38] Machinery costs by field operation are available in Appendix J in Table J.1. Total machinery costs are also listed for cropped and fallowed fields in Table J.2.

[39] The "Swampbuster" program is described in section 2.1.5.2.

Table 5.21 – CPI deflated machinery costs by implement (SAFRR, 2004d)

Powered Equipment				
Tractors[a]	Annual Hours of Use (hr)	Work Rate (ha/hr)	Operating Cost (/hr)	Operating Cost (/hr)
55 h.p.	200	N/A	9.63	N/A
150 h.p.	200	N/A	37.23	N/A
170 h.p.	200	N/A	43.65	N/A
275 h.p	200	N/A	41.20	N/A
400 h.p.	200	N/A	57.40	N/A
Swathers				
20 ft	60	3.84	38.75	10.08
24 ft	100	4.65	26.58	5.71
30 ft	100	5.67	28.77	5.08
36 ft	100	6.68	28.77	4.31
Combines				
Class 5	120	4.05	65.04	16.07
Class 6	150	4.86	64.00	13.18
Class 7	180	6.07	67.66	11.15
Class 7+	180	7.28	76.30	10.47
Drawn Equipment				
Seeder	Annual Hours of Use (hr)	Work Rate (ha/hr)	Operating Cost (/hr)	Operating Cost (/hr)
20 ft	100	3.24	15.87	4.90
24 ft	150	3.64	13.47	3.70
30 ft	150	4.86	21.81	4.49
40 ft	150	6.07	18.81	3.10
50 ft	150	8.09	22.60	2.79
Sprayer				
60 ft	60	10.93	8.07	0.74
95 ft	60	16.59	14.76	0.89
110 ft	60/120	21.45	17.70/8.85	0.82/0.41
Swathers				
24 ft	100	4.65	6.29	1.35
30 ft	100	5.67	6.66	1.18
36 ft	100	6.68	7.97	1.19

Note: [a] Operating costs per hectare and work rates are not listed for tractors because they are dependent on the operation being performed.

Therefore, in the simulation, the farm operator would receive a payment through crop insurance if the average yield of a quarter section of a certain crop was below 70% of their average farm yield for that crop as determined by the program.

The costing parameters used within the crop insurance calculator as supplied by Hulston (2005) were assumed to remain constant over the simulation period, although commodity prices and crop yields changed from year to year. Changes in the average farm yield for each crop and the stochastic nature of prices caused fluctuations in the premium the farm operator paid each year to enroll in the program. It was assumed that the farm operator received the 10% experience discount on premiums given to those that utilize crop insurance each year.

Crop insurance coverage prices are forecasts for the crop year price and are determined by SCIC in consultation with Agriculture and Agri-Food Canada (AAFC) (Hulston, 2005). The program price used in the simulation was therefore a forecast of the actual price calculated in the simulation. This forecast price was assumed to be the expected price from the same equation that was used to calculate the price used for revenue calculations (i.e. the expected value of the error was zero). However, because there are strict rules regarding over-coverage, the crop insurance price was bound to be within 20% of the actual price used in the simulation. This assumption implies that when the price forecast does not fall within the 20% range, the forecasters were able to utilize other knowledge about factors affecting prices that allowed them to forecast a price within the bounds set.

The program yield was updated each year through the same process that SCIC uses (Hulston, 2005). It is a weighted average farm yield for each crop grown on the farm and was calculated using the following equation:

$$PY_t^m = y_{t-1}^m * 0.10 + PY_{t-1}^m * 0.90, \tag{5.11}$$

where *PY* represented the program yield for crop *m* and *y* was actual yield. Therefore, the program yield for the current year was a weighted average of the farm operator's actual yield in the previous year and their program yield from the previous year.

5.2.3.2 Canadian Agricultural Income Stabilization Program

The CAIS program is a relatively new farm safety net program offered to Canadian farm operators. The program is a federally funded program that offers protection to farm operators that experience negative deviations from their average level of returns. In order to participate in the program, a farm operator selects a protection level that ranges from 70%-100%. The farm operator is then required to deposit a specified amount determined by the protection level they select and their average level of returns to a CAIS approved institution. The deposit guarantees the farm operator access to government payments made through the program. If the farm's returns are below the protection level selected, then a program payment is triggered. The protection levels are split into three tiers, 0%-70% (tier 3), >70%-85% (tier 2), and >85%-100% (tier 1). In tier 3 of the program, protection of returns is shared at a ratio of 20:80 between the farm operator and the government, while protection is shared at a ratio of 30:70 for tier 2 and 50:50 for tier 1 of the program. To provide an example, participation in tier 3 of the program requires the farm operator to deposit a dollar amount equal to 20% of their average level of returns that falls within this tier of the program. If the farm operators returns were \$50,000, then the farm operator would be required to deposit \$7,000 (\$50,000*0.70*0.20) and would be entitled to as much as $28,000 in government payments should their returns in a given year fall to $0. It is not known yet whether the majority of farm operators will participate in the program, though given the program benefits, it is expected many will. Therefore, the CAIS program was included in the present study.

The CAIS program within the simulation was modeled using the Canadian Agricultural Income Stabilization Program Handbook (AAFC, 2004). The protection level chosen for the simulation was 85%, which means that if the farm operator participated in the CAIS program and their level of returns fell below 85% of their average level of returns, a payment was triggered. This protection level represented tier 2 and tier 3 of the three tier program.

The average level of returns for the CAIS program is an Olympic 5-year average margin for allowable income and expense items. An Olympic 5-year average margin is calculated by removing the high and the low margins during the 5-year period. This margin is called the farm operator's reference margin. Within the simulation this was calculated using crop revenues and crop insurance payments less all costs used in this research study except for drainage costs. Drainage costs are not allowable expenses under the CAIS program. Five margins were needed in order to calculate an initial reference margin. This was accomplished by simulating the five years previous to the first year. The calculation was the same as those performed in each year of the simulation except that no drainage occurred in these years and the stochastic price for each of the five years was solely based on the starting prices and estimated error components. Previous year's prices were not included in the price calculations. Therefore, each of the years used to calculate the first year reference margin was separate from each other and separate from the rest of the simulation model. Performing the calculation in this manner ensured that the initial CAIS reference margin computation did not impact the results.

The CAIS deposit was treated as a reduction in cash flow, since farm operators do not have access to these funds unless a program payment is triggered. At the 85% level of protection, the farm operator was required to deposit a dollar amount equal to 20% of the 0%-70% range of their reference margin plus 30% of the 70%-85% range of their reference margin. For example, if a farm operator's reference margin was $50,000, then the amount that they would require to have on deposit would equal:

$$(\$50{,}000 * 0.70 * 0.20) + (\$50{,}000 * 0.15 * 0.30) = \$9{,}250 \tag{5.12}$$

In the simulation, the farm operator received payments under the program when their program margin fell below their protection level of 85%. Payments under the program were made in the following manner, for any margin declines below 70% of the farm operator's reference margin, payments under the program were comprised of 80% government funds and 20% farm operator withdrawals from their CAIS account until their margin reached 70% of their reference margin. The farm operator also received program payments comprised of 70% government funds and 30% farm operator withdrawals form their CAIS account until their margin reached 85% of their reference margin. For margin declines that were between 70% and 85% of the reference margin, the farm operator only received payments comprised of 70% government funds and 30% farm operator withdrawals from their CAIS account until their margin reached 85% of their reference margin. For example, if a farm operator's reference margin was once again $50,000 and their program margin for the year was $20,000, their payments and withdrawals under the program would be as calculated in equations (5.13) and (5.14). The first equation indicates the payment the farm operator would receive from the government and the second is the amount the farm operator would be required to withdraw from their CAIS account.

$$(\$50{,}000 * 0.70 - \$20{,}000) * 0.80 + (\$50{,}000 * 0.85 - \$50{,}000 * 0.70) * 0.70 = \$17{,}250 \quad (5.13)$$

$$(\$50{,}000 * 0.70 - \$20{,}000) * 0.20 + (\$50{,}000 * 0.85 - \$50{,}000 * 0.70) * 0.30 = \$5{,}250 \quad (5.14)$$

The CAIS program also makes payments to farm operators when their program margin becomes negative. Payments for negative margins are made at the rate of $0.60 for every $1 of negative margin. However, there are additional rules regarding negative margins: a farm operator can not receive payments for negative margins more often than two years out of five, their reference margin must be positive, if the farm operator did not participate in crop insurance, their negative margin benefit is reduced by 60% of the payment they would have received under crop insurance, and government payments are limited to 70% of a farm operator's reference margin. These rules were all modeled within the simulation. In the simulation, when a farm operator's reference margin was negative, they simply received no payments under the CAIS program.

5.2.4 Drainage Relationships

The model assumed that the farm operator could drain all wet areas on every quarter section through the use of contour drainage. No wet areas would remain upon completion of the drainage project. This assumption was made since there was no way to determine which wet areas could be drained through contour drainage and how much would remain on each quarter section. If the study area was surveyed to determine which wet areas would be economically feasible to drain through contour drainage, the model could be adjusted accordingly and further conclusions could be made on how much drainage would occur on each quarter section over the period of the simulation. However, since the objective of this study was to estimate the financial gains/losses obtained by a farm operator through the use of contour drainage and not whether it was actually feasible to drain a given quarter section using contour drainage, it was not necessary to know whether contour drainage could be utilized on a specific quarter section.

5.2.4.1 Drainage Costs

Drainage costs varied with the number and hectares of wet areas on each quarter section. Drainage costs were comprised of costs for construction of ditches, rehabilitation costs, and ditch maintenance costs. The figures for the total cost of drainage (ditching costs and rehabilitation costs) were compared to estimates of drainage costs per hectare from existing research; specifically the range of drainage costs for surface projects in Saskatchewan ($150-$990/ha) estimated by the Saskatchewan Wetland Conservation Corporation (1993). The latest annual consumer price index (CPI) for Canada for all goods was used to update this range to current prices (Statistics Canada, 2004). This yielded a range of $180-$1,190/ha that was used to establish total drainage costs. Mean total drainage costs for projects conducted by the farm operator during the simulation fell within this range.

5.2.4.1.1 Ditch Construction Costs

A scraper was required in order to construct drainage ditches. Construction costs for ditches were calculated by multiplying the necessary ditch length by the number of hours required to complete a meter of ditch and the appropriate machinery cost per hour for the scraper. Costs associated with scrapers are listed in Table 5.22.

Table 5.22 – CPI deflated drainage equipment costs (SAFRR, 2004d)

Scrapers - Owned	Annual Hours of Use (hr)	Operating Cost (/hr)	Capital Cost ($)
6.5 yd	80	5.28	16,883
8.5 yd	80	7.55	24,146
Scrapers - Rented			
6.5 yd	80	37.01	N/A
8.5 yd	80	52.93	N/A

The length of ditch required to drain a quarter section was calculated using the following regression equation estimated from data available in other RMs in Saskatchewan; Churchbridge and Langenburg (RMs 211 and 181, respectively). The equation was as follows:

$$Drainage_i = \beta_0 + \beta_1 \Delta WetArea + \beta_2 \Delta Ponds + \varepsilon_i, \qquad (5.15)$$

where $Drainage_i$ was the estimated length of ditch to drain quarter section *i*, *WetArea* was the total area of wetlands on the quarter section, and *Ponds* was the number of wetlands on the quarter section. The estimation was similar to the regression conducted in section 3.3. It was assumed that changes in wetlands and the number of wetlands on a quarter section would be a reasonable indicator of the length of drainage ditch needed to drain a quarter section. As in section 3.3, the 421 quarter sections where drainage ditches had been constructed out of the 654 in the data source were used to estimate the parameters.

The results of the regression suggested that larger losses in wetland area and numbers of wetlands would be consistent with greater lengths of drainage ditches (Table 5.23). However, if equation 5.15 resulted in a high estimate for the length of ditch needed to drain a quarter section relative to the total area of wetlands and cropped basins on the quarter section, it would only become economically feasible to perform drainage on the quarter section during periods of sustained high prices and yields.

Equation 5.15 was in agreement with Rousseau (1983) who found that costs per hectare drained increased with the number of wetlands on each quarter section. Ditch lengths, however, were calculated using equation 5.15 with an estimated error component for each quarter section. Including the error component resulted in a range of costs per hectare drained rather than a constant value, which could result in violations of Rousseau's (1983) finding. Rousseau's (1983) findings were for the general case, while the inclusion of an error component in the present study simulated the heterogeneity of drainage costs that occurs in reality. For example, two quarter sections could have the exact same hectares and numbers of wet areas, but the cost per hectare to drain them may vary because of other factors such as topography of the quarter section, the distribution of the wet areas within the field, and the farm operator's abilities with a scraper.

Table 5.23 – Ditch length estimation results

Variable	Estimated Coefficient
ΔWetArea	-0.0523***
	(0.0070)
ΔPonds	-0.0179***
	(0.0034)
Constant	0.3204***
	(0.0686)
R^2	0.2907
No. of Records	421
Std. Dev.	0.8304

Notes: * Represents significance at the 10% level, ** at the 5% level and * at the 1% level. Heteroskedasticity was adjusted for using White's heteroskedastistic-consistent covariance matrix.**

The error component for the equation was estimated using a standard normal distribution and then scaling the error by the standard deviation of the equation. The error component for each quarter section was estimated only once. Therefore, ditch construction costs associated with a particular quarter section did not change for each iteration. The addition of the error component did result in negative values for ditch lengths needed on certain quarter sections, thus a minimum ditch length was established at 200 meters. This minimum length was representative of quarter sections in the RM.

The duration of time it took to construct one meter of ditch using a scraper was determined by calibrating drainage costs so they were within the assumed range of $180-$1,190/ha. The time also needed to be an appropriate average for contouring operations. This process resulted in an estimate of 0.20 hr/m, which corresponds to 12 min/m. It is important to note that the time to construct one meter of drainage ditch was based on an 8.5 yard scraper. There are two sizes of scrapers used in the study, a 6.5 yard and an 8.5 yard scraper. It was assumed that it would take 30% longer to construct drainage ditches with the smaller scraper, since the 8.5 yard scraper had a 30% larger capacity. Therefore, the time to construct one meter of ditch with the 6.5 yard scraper would be 0.26 hr or approximately 16 min.

5.2.4.1.2 Rehabilitation Costs

Rehabilitation costs are those incurred to prepare the land for crop production. Brushing, breaking and rock picking are examples of operations that may be necessary prior to seeding crops in wetland areas. Therefore, rehabilitation costs were added for wetland areas only and not cropped basins since cropped basins already produced crops. A breaking disk was assumed to be rented rather than purchased by the farm operator since the areas drained were generally small. Costs associated with breaking disks used in the analysis are listed in Table 5.24. Rehabilitation costs per hectare were estimated from Wanchuk (1986) who lists rehabilitation costs at an average of $144/ha. Within the simulation, rehabilitation costs of $200/ha were used.

Table 5.24 – Deflated breaking disk rental costs by implement width (SAFRR, 2004d)

Breaking Disk	Annual Hours of Use (hr)	Work Rate (ha/hr)	Operating Cost (/hr)	Operating Cost (/hr)
10 ft	150	2.23	22.83	10.26
14 ft	150	3.04	30.32	9.99

5.2.4.1.3 Maintenance Costs

Maintenance costs noted in previous research vary in magnitude. Danielson and Leitch (1986) used 3% of initial costs for both surface and subsurface projects in Minnesota. Wanchuk (1986) estimated maintenance costs for surface drainage projects to be less than 1% of initial costs in Alberta. Myhre (1992) used 2% of initial costs for operating and maintenance costs of a surface project in Alberta. Danielson (1989) used 1% of initial costs for drainage projects in North Carolina. Lastly, Rigaux and Singh (1977) used 7% for government funded drainage infrastructure projects. Of the studies listed, the most relevant estimates were those for projects in Alberta and 1.5% appeared representative of the findings for the two Alberta studies. Therefore, in the current study, maintenance costs were calculated as 1.5% of initial costs. A scraper was utilized for maintenance of existing ditches. It was assumed the farm operator spent 1.5% of the time they spent originally constructing ditches going over existing ditches performing maintenance.

5.2.4.2 Number of Years to Complete Drainage on a Quarter Section

The number of years it took to complete a drainage project on a quarter section was assumed to be three years and based on observations made by DUC. The proportion of the contouring that was conducted during each of the three years was 0.40, 0.35 and 0.25. The lowest proportion of drainage was conducted in the final year of the project because it was during this final year that rehabilitation of drained lands occurred. The schedule, however, was a guide, as the time available for drainage had an impact how many hours a farm operator could devote to drainage projects each year. For example, if there was insufficient time for the for the farm operator to complete 40% of the project in the first year, the hours of work not completed were added to the following year's workload. If they completed the first year's work on the first project, the farm operator began work on another project.

5.2.4.3 Nuisance Costs

Nuisance costs are those that arise from maneuvering around wetland obstacles within fields and were considered in the calculations of both input costs and machinery costs (Danielson and Leitch, 1986; Goldstein, 1971). It was assumed that only wetlands resulted in nuisance costs because it was assumed that cropped basins were farmed without difficulty each year.

Estimates of nuisance costs were based on the limited research available, the best source being Desjardins (1983). From this study, nuisance factors were calculated for one wetland and four wetlands in a quarter section for various machinery widths. The nuisance factors represented percent increases in time spent in each quarter section resulting from maneuvering around wetlands. The cost of maneuvering around wetlands was then estimated by multiplying the additional time spent in a quarter section by machinery operating costs. Results are indicated in Table 5.25. The findings illustrated that nuisance costs increased with the size of the implement and the number of wetlands.

Further information with respect to nuisance costs, from Desjardins (1983), was taken from an analysis of circular shaped objects at different locations within a quarter section. However, regular shaped objects did not have as large an impact on costs as did obstacles such as wetlands. Table 5.26 indicates the effect of a circular shaped object on

Table 5.25 – Nuisance factors by number of wetlands and implement width per quarter section

Implement Width	One Wetland	Four Wetlands
20 feet	10.98%	11.59%
28 feet	11.70%	15.96%
32 feet	12.61%	18.02%
36 feet	16.56%	19.87%

Note: The wetlands in each of the two scenarios comprised the same area (9.4 ha) within the quarter section. Approximate field configurations are given in Appendix K in Figures K.1 and K.2.

Table 5.26 – Nuisance factors for regular shaped obstacles by machinery width and obstacle location

Implement Width	Obstacle Size (ha)	Corner	Center
14 feet	10.12	0.43%	2.55%
20 feet	10.12	0.71%	3.53%
30 feet	10.12	0.94%	5.66%
68 feet	10.12	4.08%	12.24%

Note: Approximate field configurations are given in Appendix K in Figures K.3 through K.5.

Table 5.27 – Nuisance factors for regular shaped obstacles by obstacle size and field location

Obstacle Size (ha)	Location	Increase in Cost
10.12	Center	4.17%
10.12	Side	1.42%
10.12	Corner	1.32%
4.05	Center	2.67%
4.05	Side	0.91%
4.05	Corner	1.32%

Note: Approximate field configurations are given in Appendix K in Figures K.3 through K.5.

machinery operating costs by implement width, while Table 5.27 indicates how different sized circular shaped obstacles in various locations affect machinery costs.

The estimates in Tables 5.26 and 5.27 also reveal that nuisance costs increased with implement width. It was also apparent that nuisance costs were lower for obstacles along the side or in the corner of quarter sections. The estimates for obstacle size were similar to findings by Accutrak Systems Ltd. (1991), which suggested that increases in wetland size did not substantially increase costs associated with maneuvering around wetlands.

From the analysis of nuisance costs by Desjardins (1983), a nuisance factor table was developed for use in the simulation (Table 5.28). Nuisance costs were assumed to increase as farm size increased and as the number of wetlands within a quarter section increased. Nuisance costs increased with farm size because these farms were assumed to have larger machinery complements and it was shown that it would be more costly to maneuver larger equipment around wetland obstacles. More wetlands within a quarter section were also shown to increase nuisance costs at an increasing rate.

The following example demonstrates how nuisance costs were calculated within the simulation. If the nuisance factor for a quarter section was 15% (Table 5.28), the farm operator would incur 15% more machinery operating expenditures in this quarter section than in a quarter section without wetlands. In a quarter section where machinery costs would otherwise be $1,000 if there were no wetlands, $150 of additional machinery costs would be added to account for the nuisance of having to maneuvre around wetland obstacles.

Table 5.28 – Wetland nuisance factors that increase at an increasing rate, by farm size and number of wetlands in a quarter section

Number of Wetlands	Farm Size (number of quarter sections) 4	8	12	16	20
1 - 3	8.0%	9.0%	11.0%	14.0%	18.0%
4 - 6	9.0%	10.0%	12.0%	15.0%	19.0%
7 - 9	11.0%	12.0%	14.0%	17.0%	21.0%
> 9	14.0%	15.0%	17.0%	20.0%	24.0%

The farm operator also incurred additional input costs in the form of input waste. Input waste was calculated in a similar manner as additional machinery operating expenditures. Since overlap areas could not be explicitly calculated, it was assumed that input waste would be positively related to the additional time spent in a field. An overlap factor of 10% was used and it was assumed that the nuisance factor multiplied by this overlap factor would approximate the area overlapped with inputs by the farm operator. Input waste was then calculated by multiplying this additional area by the per hectare cost of inputs for the appropriate crop. Input costs for the quarter section, which were calculated based on standard per hectare costs were multiplied by the appropriate nuisance factor and then multiplied by 10% for overlap. Using the same example that was used for machinery costs, if total input costs for a quarter section without obstacles were $10,000, the farm operator would incur an additional $150 ($10,000 x 0.15 x 0.10) in input costs. In this example, input costs were 1.5% greater than that of a field without wetland obstacles. Accutrak Systems Ltd (1991) also used an overlap factor of 10%; however, they used additional distance traveled to calculate overlapped area and input waste.

5.2.4.4 Yields in Wetlands and Cropped Basins

There was no literature that compared yields on drained areas to upland yields since wet areas generally comprise a small component of most fields. There was, however, anecdotal evidence provided by Lyseng (2002) and Wanchuk (1986) that suggested yields could be greater on drained areas for reasons such as better soil and moisture availability during dry periods (Wanchuk, 1986; Lyseng, 2002). Whether or not yield differences continue indefinitely was unknown. Therefore, yields in drained areas were assumed to be the same as those for the rest of the quarter section.

The only literature available pertaining to the frequency of crop losses in cropped basins was Pearson and Kulshreshtha (2002). In their research, Pearson and Kulshreshtha (2002) analyzed several different CDA projects across Saskatchewan and determined how often yields within cropped basins were 0 tonnes/ha. They found that yields of 0 tonnes/ha in cropped basins were experienced anywhere from two to nine years out of every ten. It appeared that these losses were highly dependent on location. In the absence of any further information for the RM of Emerald, it was assumed that yields of 0 tonnes/ha were experienced in cropped basins 4 out of 10 years.

5.2.4.5 The Drainage Decision

All drainage projects were assumed to be contour drainage projects carried out by the farm operator. Each project was defined in terms of an entire quarter section; the farm operator drained all wet areas on a quarter section or conducted no drainage at all in that particular field. It could have been assumed that decisions to drain were made for each wet area on each quarter section. However, it was determined that this would have significantly increased the difficulty of modeling drainage projects without substantially improving the results of the present analysis.

Only quarter sections that were owned by the farm operator were considered for drainage as discussed in section 5.1.1. It was assumed that farm operators used a 20-year planning horizon for drainage projects. Drainage projects that were economically feasible over this 20-year period were conducted by the farm operator. The life of the drainage project was assumed to be infinite as maintenance costs of 1.5% of initial costs were included in the analysis. This approach was similar to that used by several other researchers whom used project lives or planning horizons in the range of 15 to 25 years in their analyses (Cecile et al., 1985; Danielson and Leitch, 1986; Leitch, 1983; Kanwar et al., 1983; Huel, 2000). Rigaux and Singh (1977) mentioned that a drainage system would become ineffective after 15 years without maintenance because of silt deposits, vegetation growth and erosion. They imply, however, that through maintenance the effective life of such projects could be extended. With regards to contour drainage, there are few structures that need to be maintained or replaced. Therefore, it is possible that the life of such projects is infinite. Farm operators simply need to maintain their ditches by going over their ditches with a scraper each year (Manitoba Agriculture, 1985).

The farm operator in the simulation had to decide whether drainage was economically feasible to conduct, and if so, which quarter sections would be drained. The farm operator based decisions to drain on expected net present values (NPV) of drainage projects and used returns over the previous 5-year period for NPV calculations. Prices and yields used for the initial 5- year period were those calculated for the initial CAIS reference margin, as described in 5.2.3.2.

For the farm operator's analysis of the economic feasibility of drainage projects, incremental revenues and expenses were calculated each year over the 20-year planning horizon. The first three years of the NPV calculation had negative cash flows consisting of ditch construction costs, maintenance of constructed ditches and rehabilitation costs. Maintenance costs were also incurred each year after completion of the project.

The year after completion of construction of drainage ditches and rehabilitation of wetland areas, benefits from drained lands began to accumulate. Yearly incremental revenues and costs for drained lands were calculated as averages rather than following the rotation exactly for ease of calculation. This procedure is best explained through the use of an example. Sample data for calculating returns over the 3-year canola-wheat-fallow rotation are shown in Table 5.29. Equations 5.16, 5.17 and 5.18 calculate the average returns per hectare over the previous 5-year period for canola, wheat, and summerfallow, respectively. Equation 5.19 reveals that an additional hectare of land provides a return of $70.52. In the actual calculation used in the simulation, payments received through participating in crop insurance and the CAIS programs were also included.

Table 5.29 – Sample farm data for calculating average returns per hectare over the previous 5-year period for the canola-wheat-fallow rotation

	Canola	Wheat	Fallow
Last Year's Price ($/tonne)	$250	$175	$0
Price Two Years Ago	$350	$125	$0
Price Three Years Ago	$300	$150	$0
Price Four Years Ago	$325	$180	$0
Price Five Years Ago	$275	$190	$0
Last Year's Yield (tonne/ha)	0.85	1.90	0.00
Yield Two Years Ago	1.15	1.60	0.00
Yield Three Years Ago	1.25	2.20	0.00
Yield Four Years Ago	1.05	1.95	0.00
Yield Five Years Ago	1.00	1.70	0.00
Machinery Costs ($/ha)	$40	$40	$12
Input Costs	$150	$140	$25

$$(\$250*0.85+\$350*1.15+\$300*1.25+\$325*1.05+\$275*1.00)/5-(\$40+\$150)=\$131.25 \quad (5.16)$$

$$(\$175*1.90+\$125*1.60+\$150*2.20+\$180*21.95+\$190*1.70)/5-(\$40+\$140)=\$117.30 \quad (5.17)$$

$$\$0-(\$12+\$25)=-\$37 \quad (5.18)$$

$$(\$131.25+\$117.30+(-\$37))/3=\$70.52 \quad (5.19)$$

Incremental returns from drained wetlands were received each year, whereas incremental returns from cropped basins would only be received in years when precipitation was such that the yield in the cropped basins would have been 0 tonnes/ha. Thus, incremental returns from cropped basins were lower than that of wetlands. Since it was assumed that yields of 0 tonnes/ha were experienced in 4 out of every 10 years, then yearly incremental returns from a drained cropped basin were equal to 40% of the margin calculated in equation 5.19 ($28.21).

The calculations performed in equations 5.16 through 5.19 did not include reductions in nuisance costs since they were accounted for in a separate calculation. They were accounted for by calculating pre-drainage and post-drainage average nuisance costs. Once again average nuisance costs were based on the rotation used in the simulation and were separated into input waste and additional machinery cost components. The pre-drainage nuisance costs were then subtracted from the post-drainage nuisance costs for each of the nuisance cost components and this difference was added to the NPV calculation. Post-drainage nuisance costs were zero since it was assumed that the farm operator was able to drain all wet areas using contour drainage.

The NPV of each project was then calculated by discounting each of the yearly cash flows and then summing them over the 20-year planning horizon. The farm operator used these NPV values and their cash flow in the current year to make drainage decisions. Projects with positive NPVs were assumed to be undertaken by the farm operator. Cash flow in the year in which they wished to begin a new drainage project needed to be positive since farm operators would likely not make any unnecessary expenditures in years of negative cash flow. If the farm operator decided to conduct drainage, they attempted to drain all quarter sections that had positive NPVs in descending order of NPV (i.e. the field in which the farm operator deemed to have the highest NPV was scheduled to be drained first). The farm operator continued constructing drainage ditches until the time available to conduct drainage was exhausted or they had completed all drainage activities scheduled for that year. Any portion of a project that was scheduled to be conducted in a particular year, but was not completed due to a lack of time was added to the subsequent year's drainage schedule.

Once construction of drainage ditches was completed, the farm operator began rehabilitation of drained lands. The only portion of rehabilitation assigned a time component was breaking since equipment costs and work rates were available in the Farm Machinery Custom Rate and Rental Guide (Table 5.1) (SAFRR, 2004d). Crops were sown in drained lands the year following the completion of both construction of drainage ditches and rehabilitation of drained lands.

Any projects that were initiated were completed by the farm operator regardless of whether cash flow was positive or negative in the years following the commencement of a project. Projects that were scheduled, but not started due to a lack of cash flow or time were subject to a NPV and cash flow analysis in each of the subsequent years for the duration of the simulation. A NPV calculation was performed each year because, for example, a project that was initially marginally economically feasible could become economically infeasible given that the 5-year average return fluctuated due to differences in commodity prices and crop yields each year.

Since the farm operator based decisions to drain on the performance of the farm in previous years, expected returns from drainage determined by the farm operator differed from actual returns. This was caused by the stochastic nature of crop yields and commodity prices. A drainage project that was expected to have a positive NPV could have a negative impact on the overall farm NPV if actual prices and/or yields over the life of the project were lower than those the farm operator used when calculating the economic feasibility of the project. The stochastic nature of time available to conduct drainage could also influence the actual returns from drainage. When few workdays were available in the fall, a project could take more years than planned to complete, reducing the NPV of a project since positive cash flows get delayed and therefore discounted at a higher rate.

5.2.4.6 Determining the Discount Rate for the Analysis

Capital Market Line theory (section 4.1.1) was used to determine the discount rate for the present analysis. This required estimates for all variables indicated in equation 4.4. Estimates of stock market returns in Canada over the 25-year period from 1976-2000 indicate an average return of 14.03% with a standard deviation of 15.23% (Copeland et al., 2005). The risk premium ($\bar{r}_M - r_f$) associated with the stock market over this time period was 4.91% (Copeland et al., 2005)[40]. The most recent average yield on 1-3 year Government of Canada Marketable Bonds was used as the risk-free rate of return. The rate of return on these bonds was about 3.25% (Statistics Canada, 2005).

No estimate of the standard deviation of returns, σ_p, was available for a Western Canadian grain operation. Therefore, it was determined through the use of simulation analysis. The procedure for estimating σ_p by this method was outlined in Copeland and Antikarov (2003). The equation is listed below:

$$\bar{r}_p = \frac{NPV_1 - NPV_0}{NPV_0}, \qquad (5.20)$$

where NPV_0 was an expected NPV for time periods 0 through n, and NPV_1 was a NPV distribution for time periods 1 through n determined through the use of Monte Carlo simulation. The use of simulation analysis to determine $\bar{r}_p$ yielded an estimate of σ_p. Two separate simulations of 1,000 iterations were used to determine σ_p. Two simulations were performed to ensure that σ_p was stable across simulations. Both simulations yielded similar values for σ_p, which was approximately 33.07%. Using equation 4.4, $\bar{r}_p$ was then calculated as follows:

$$3.25 + \left[\frac{4.91}{15.23}\right] * 33.07 = 13.91 \qquad (7)$$

The discount rate of 13.91% determined through the use of the simulation model was deemed a maximum value since lower risk involved in grain farming suggests that the discount rate should be less than that used for livestock operations. The level of risk involved in a grain operation is likely lower than that of livestock operations because grain operations produce several different crops. Farm operators are able to reduce risk by shifting hectares to crops forecasted to have higher prices. Different crops also have different growth patterns and are sensitive to weather at different times of the year, which reduces risk as well. Analyses of risk for cattle operations, have yielded discount rates of 10.21% and 12.34% (Miller, 2002; Bauer, 1997). In research conducted in the pork industry, Duku-Kaakyire (2003) used 15% as a discount rate. Since risk involved in grain farming was less than that associated with livestock operations, 10% was determined an appropriate discount rate for NPV calculations. Danielson and Leitch (1986), Cecile et al. (1985), Leitch (1983), Rigaux and Singh (1977), and Found et al. (1975) also used discount rates of around 10% in their respective analyses of drainage.

5.3 Overview of the Analysis Performed

This section outlines the various scenarios used to investigate the economic feasibility of drainage, potential wetland loss, and policy implications for wetland conservation in the RM of Emerald. Several sensitivity analyses were also performed to determine how estimates responded to changes in assumptions used in model. In this section, justification for performing each scenario and sensitivity analysis is presented along with the different assumptions used in each analysis. Nine different scenarios and seven sensitivity analyses were used in total.

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[40] The expected return less the risk-free interest rate is known as the risk premium (Ross et al., 2003).

5.3.1 Initial Model Assumptions

The assumptions made for the representative farm used in Scenario 1 are outlined in Table 5.30. All subsequent scenarios and sensitivity analyses used the same assumptions for the majority of the variables. Any differences in these assumptions will be noted where appropriate.

The assumptions relating to the farm were largely based on Census of Agriculture data for the study area. The representative farm was comprised of eight quarter sections of land and the farm operator followed a canola-barley-flax-wheat-summerfallow rotation. Mean annual revenues for the farm were \$137,000, which would rank the farm within the top quartile of all cash crop farms within the study area. A farm of this size was chosen since Census of Agriculture data for 2001 and 1996 suggested that smaller farms are disappearing, whereas large farms continue to expand (Biggs, 2004). A rotation that included summerfallow was utilized because there was still a considerable amount of summerfallow within the RM of Emerald in 2001 (Biggs, 2004).

Table 5.30 – Initial representative farm set-up

Farm Assumptions	
Number of quarter sections	8
Land base	Randomly drawn for each iteration
Percent of land owned by farm operator	75%
Crop rotation	Canola-barley-flax-wheat-summerfallow
Crop insurance	All cropped hectares covered
CAIS program	Farm enrolled in program
Discount rate	10%
Starting commodity prices	10-year average (1993-2002)
Drainage Assumptions	
Area drained	Both wetlands and cropped basins
Scraper treatment	Needs to be purchased by farm operator
Drained area yield relative to rest of field	No difference
Cropped basin losses	4 out of every 10 years
Years to conduct drainage	3
Time to construct 1m of ditch	0.20 hr
Rehabilitation costs per hectare	\$200/ha
Number of passes with breaking disk	1

The quarter sections were randomly drawn for every iteration[41]. Changing the quarter sections for each iteration, however, generated large standard deviations and wide confidence intervals for most outputs. This indicated that the characteristics of the quarter sections that a farm operator owned dictated the economic feasibility of drainage. For farm programs, since the majority of hectares of crops grown in the study area were enrolled in the crop insurance program in 2001, the representative farm was expected to participate in the program as well (Hulston, 2005). The farm was also enrolled in the CAIS program, since it was expected that farm operators would take advantage of this program. A 10% discount rate was used as determined in section 5.2.4.6. Ten-year average commodity prices were chosen as the starting point as this was deemed to the best reflection of future prices.

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[41] The intuition behind changing the fields for every iteration is discussed in section 5.1.2.

For initial assumptions pertaining to drainage, it was assumed that the farm operator had not previously drained any land. Thus, the quarter sections did not initially have any ditches on them to be maintained. In the initial scenario, the farm operator was required to purchase a scraper before conducting drainage. Both wetlands and cropped basins were assumed to be drained as it seemed appropriate that a farm operator would want to remove as many areas affected by water as possible. Including the opportunity to drain cropped basins allowed the farm operator to spread the capital cost of the scraper over more hectares. As discussed earlier, in the absence of information relating to the frequency in which yields in these areas were 0 tonnes/ha, the frequency was assumed to be 4 out of every 10 years. No yield advantage was assumed for the drained areas, also discussed earlier.

5.3.2 Simulation Scenarios

The first three scenarios dealt with how costs pertaining to the scraper were incorporated into the analysis since costs associated with the scraper were the main costs incurred for conducting drainage projects. They represented the main scenarios that analyzed the economic feasibility of drainage for a representative farm in the RM of Emerald. The first scenario assumed that the farm operator purchased a scraper before conducting any drainage on their land as illustrated in the assumptions in Table 5.30. In the second scenario, the farm operator rented a scraper. Renting a scraper did not involve the large initial cash outlay that purchasing did and therefore may be an attractive alternative for those contemplating drainage projects. The third situation assumed that the farm operator already owned a scraper since farm operators in the study area do own scrapers and nearly all of the quarter sections had previously constructed drainage ditches on them. The first two scenarios assumed that the farm operator had not previously conducted any drainage on their land and the farm operator was contemplating drainage as a means to expand their cultivated land base. However, the third scenario assumed that the farm operator was maintaining existing drainage infrastructure and contemplating investing in new projects. Capital costs and operating costs for scrapers were listed in Table 5.22.

The fourth scenario analyzed the economics of draining only wetlands rather than both wetlands and cropped basins. Two cases were analyzed; in the first the farm operator drained both wetlands and cropped basins, whereas in the second the farm operator only drained wetlands. The purpose of this scenario was to analyze whether the farm could use this strategy to improve its economic performance, since cropped basins do provide some returns to the farm operator in their current state. In this scenario, the farm operator was assumed to be initiating drainage and purchased a scraper prior to conducting drainage projects

Scenario five dealt with how the farm size influenced the results. This analysis was performed since farms in the RM of Emerald vary in size and evidence suggested that farm size is growing. Five farm sizes were utilized in this scenario: 4, 8, 12, 16 and 20 fields. The objectives of this scenario were to determine how the economics of purchasing a scraper changed as farm size increased and to investigate how returns to renting a scraper and performing additional drainage changed as farm size increased. A range of incentive payments that could be offered to farm operators to forgo drainage were estimated in this scenario. However, incentive payments are only one of a host of policy instruments that could be used to conserve wetlands. Successful wetland conservation programs could be developed that do not require the use of direct payments to producers.

Scenario six specifically addressed nuisance costs associated with wetlands since nuisance costs of wetlands have been noted to be a potentially important factor in the drainage decision (Leitch, 1983). It was difficult to accurately determine nuisance costs; therefore it was important to include a scenario that addressed the issue separately. The analysis compared three different cases pertaining to nuisance costs for two different farm sizes. Farms comprised of 8 and 16 quarters sections were used to demonstrate the impact that larger machinery complements could have on nuisance costs. The first nuisance cost situation assumed that wetlands were costless to farm around. For the second, an additional nuisance cost table (Table 5.31) was developed in which nuisance costs increased at a constant rate as farm size increased and as the number of wetlands within a quarter section increased. Both cases were compared to the base assumption that nuisance costs increase at an increasing rate with respect to farm size and the number of wetlands within a quarter section (Table 5.28). The farm operator was assumed to already own a scraper in this analysis and was contemplating draining additional land.

Table 5.31 – Wetland nuisance factors that increase at a constant rate, by farm size and number of wetlands in a quarter section

Number of Wetlands	Farm Size (number of quarter sections)				
	4	8	12	16	20
1 - 3	8.0%	9.5%	11.0%	12.5%	14.0%
4 - 6	9.5%	11.0%	12.5%	14.0%	15.5%
7 - 9	11.0%	12.5%	14.0%	15.5%	17.0%
> 9	12.5%	14.0%	15.5%	17.0%	18.5%

The seventh scenario addressed the impacts of farm programs on drainage since indirect subsidies alter the returns and level of risk experienced by a farm operation. These differences in returns could potentially provide further incentives to drain lands. In this scenario, two sets of results were compared, one in which the farm operator participated in both CAIS and crop insurance and the other where the farm operator only participated in crop insurance. Both cases assumed that the farm operator already possessed a scraper and was contemplating additional drainage. Only the CAIS program was analyzed because it was noted during model testing that the CAIS program appeared to significantly alter the returns and risk involved in operating a grain farm, whereas crop insurance did not.

Scenario eight was used to analyze how using the same initial land base in each iteration could impact the results. In this scenario, the initial land base was not randomly drawn for each iteration. The analysis emphasized how the characteristics of the farm operator's land base could make drainage more or less attractive for different farm operations in the study area. In this scenario, two cases were considered, one where the representative farm had considerably more wetland area than the average per quarter section in the study area and the other where the representative farm had considerably less. The first farm was also comprised of quarter sections with an initial endowment of wetland hectares that were, on average, more economically feasible to drain, whereas the second was comprised of parcels that had an initial endowment of wetland hectares that were, on average, less economically feasible to drain. In this scenario, it was assumed that the farm operator was initiating drainage and purchased a scraper prior to draining lands.

A historical analysis of drainage was performed in the ninth scenario. This analysis was conducted to examine the impact of a different "price regime" for crop. In real terms, farm returns were higher in the past than they have been in recent years. Given the extent of drainage currently seen in the study area, it seemed appropriate to assess the effect of higher returns, as this would have affected the incentives for farm operators to drain wetlands in previous decades.

For the historical analysis, assumptions were made to best represent a historic farm operation. A representative farm of four quarter sections following a rotation of canola-wheat-summerfallow was used in the simulation. The parameters for the representative farm were changed from previous scenarios because, historically, farms were smaller and summerfallow was more common. The analysis also used an estimate of the historical values for wetland area and counts on each quarter section. This was done by adding estimates for previously drained area and counts to the current allocation of wetland area and counts[42]. To determine historic values for wetland area and counts, equation 3.1 was used. However, equation 3.1 was altered so that it included a random draw from a standard normal distribution scaled by the standard deviation of the equation for the error component and a minimum wetland area of 0.5 ha per quarter section. A minimum value needed to be established due to the large standard deviation of the equation. The minimum value was established at a value greater than zero because all quarter sections had at least one wetland historically. The error component, however, was not stochastic and was only estimated once. This meant that the historical values for wetland areas and counts were fixed for each quarter section.

Given that there were more wetlands on each quarter section, the number of years required to complete drainage on a quarter section was increased from three to four. Commodity prices used for this scenario were the average prices over the years 1960-2002; $294.58/tonne, $215.09/tonne, $541.81/tonne, and $569.80/tonne for wheat, barley, canola, and flax, respectively. Participation in the CAIS program was not modeled in this scenario, as it would not have been available to farm operators. The farm operator was also assumed to have not conducted drainage previously and purchased a scraper prior to doing so for this scenario.

5.3.3 Sensitivity Analyses

Sensitivity analyses were conducted since there was a lack of certainty about some of the parameters. Through theses analyses, the impact these parameters have on the results was determined. Parameters that generate large changes in the results could be considered for further research.

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[42] Previously drained areas were estimated in section 3.3, whereas counts of historic wetlands were provided in the data source discussed in section 3.3.

The first sensitivity analysis was performed for the number of years it would take to complete a drainage project on a quarter section since DUC observations indicated that drainage projects appear to take three to four years to complete. In the scenario analyses, all drainage projects were assumed to take three years to complete. For the sensitivity analysis, the number of years to complete a drainage project was increased to four years and compared to the initial assumption. The approximate proportion of ditch construction that was conducted in each of the four years was 0.30, 0.25, 0.25 and 0.20. In this analysis, the farm operator was also assumed to be initiating drainage and purchased a scraper prior to conducting drainage projects.

Sensitivity to drainage cost assumptions was examined in the second sensitivity analysis. This analysis was performed since there were few sources of data pertaining to cost of drainage in the RM of Emerald. In the model, there were two variables that pertained to drainage costs; the time to construct one meter of ditch and rehabilitation costs per hectare. Changing the time to construct one meter of ditch had an impact on both initial ditch construction costs and maintenance costs. Two cases were evaluated in this analysis. The first case used a value for the time to construct one meter of drainage ditch of 0.15 hr/m and rehabilitation costs of $150/ha, whereas the second case used a value for the time to construct one meter of drainage ditch of 0.25 hr/m and rehabilitation costs of $250/ha. These two cases were compared to the initial assumptions of 0.20 hr/m for the time to construct one meter of drainage ditch and $200/ha for rehabilitation costs. The farm operator was also assumed to be initiating drainage and rented a scraper to conduct drainage projects.

In the third sensitivity analysis, the frequency in which yields of 0 tonnes/ha were experienced in cropped basins was considered and was performed due to a paucity of data pertaining to this variable for the study area. Two cases were investigated; the first had yields of 0 tonnes/ha in these areas in 2 out of every 10 years, whereas the second had yields of 0 tonnes/ha in 6 out of every 10 years. Both cases were compared to the initial assumption that yields of 0 tonnes/ha would be experienced in 4 out of every 10 years. It was also assumed that the farm operator was initiating drainage and purchased a scraper prior to performing drainage projects in this analysis.

The yield in drained areas relative to their upland counterparts was another variable for which little information was available; therefore, sensitivity analysis was performed. Information that was collected pertaining to yields in drained areas suggests that they could be greater than upland areas. Two sources relevant to the type of drainage examined in this study, Lyseng (2002) and Wanchuk (1986), suggested that the soil in drained areas is better than other areas of the field and that these areas have more moisture available during dry periods, leading to improved yields[43]. Two cases are considered, one in which yields in drained areas were 5% greater than upland (i.e. non-wetland) yields and another where yields were 10% greater than upland yields. The results were compared to the initial assumption that no yield advantage was experienced on drained area. In this analysis, the farm operator was also assumed to already own drainage equipment and was conducting additional drainage.

The fifth sensitivity analysis examined how the results would vary based on alternative crop rotations since different farm operators follow different crop rotations depending on such factors as commodity prices, soil type, equipment owned, and personal preferences. All simulation scenarios utilized the 5-year rotation of canola-barley-flax-wheat-summerfallow. This analysis examined the sensitivity of the results when a canola-wheat-summerfallow rotation and a continuous cropping rotation of canola-barley-flax-wheat were employed. The farm operator was also assumed to already own drainage equipment and was conducting additional drainage for this sensitivity analysis.

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[43] Changes in yield resulting from drainage projects are discussed in sections 2.2.3. However these yield increases were generally associated with subsurface and general field drainage systems.

In scenario six, sensitivity to different price assumptions were considered. This analysis was performed since determining prices over a 20-year period is difficult. To examine price sensitivity, two different price levels were utilized and compared to the results which used 10-year average prices. The first case assumed the mean prices in each year over the 20-year period were the commodity prices from 2002, whereas the second case used 5-year average prices over the period 1998-2002 (Table 5.32). It was also assumed that the farm operator was initiating drainage and purchased a scraper prior to performing drainage projects.

Table 5.32 – CPI deflated alternative starting prices for the simulation model ($/tonne)

	Wheat	Barley	Canola	Flax
2002 Price	183.96	157.24	327.85	378.21
5-year Average	163.52	133.63	317.57	299.33

The final sensitivity analysis evaluated the sensitivity of results to changes in the discount rate since no previous research pertaining to risk involved in a Western Canadian grain operation was available[44]. For the sensitivity analysis, discount rates of 8% and 12% were used and compared to the results for the assumed 10% discount rate. The farm operator was also assumed to be initiating drainage and rented a scraper to conduct drainage projects.

5.3.4 Summary Statistics

5.3.4.1 Determining the Economic Feasibility of Drainage

The two alternative actions of the farm, conducting no drainage and expanding its cultivated land base through drainage were compared using NPV, PV, and cash flow outputs from the simulation. NPVs were calculated by summing discounted cash flows over the 20-year simulation period. Perpetuity calculations were also performed to yield NPVs for the farm beyond the 20-year simulation period, as the farm was assumed to continue operations beyond year 20. The NPVs and other summary statistics were compared to determine which of the two alternative actions improved farm performance. If higher NPVs were experienced by the farm when it conducted drainage and the other summary statistics indicated drainage was a rational decision, then the farm operator would be expected to perform drainage.

NPVs were calculated in two different ways. One was a simple difference of the NPVs for the two alternative actions. The NPV of no drainage was subtracted from the NPV for the farm when it conducted drainage. This value indicated the total difference in performance between the two alternative actions.

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[44] Choice of discount rate was discussed in section 5.2.4.6.

The other NPV comparison was made in terms of the difference per hectare drained. This value was the difference between the NPVs for the two alternative actions of the farm divided by the hectares of land drained when the farm operator conducted drainage. The difference per hectare drained provided an indication of the economic benefit of drained lands. This value provides a basis for estimating economic incentives that farm operators may accept to maintain wetland resources on their land.

Other summary outputs used in determining the economic feasibility of drainage included a count of how often the NPV of drainage was greater than that of no drainage. This value was converted into a probability that conducting drainage had a greater NPV than performing no drainage. The present value of drainage costs provided another means of determining whether a farm operator should engage in drainage. If the mean present value of drainage costs was greater than the price of land in the region, then the farm operator would be expected to purchase land to expand their cultivated land base rather than perform drainage. Analyzing non-discounted cash flows also provided some insight into the economic feasibility of drainage, as increased cash flows would be important to the farm operator.

5.3.4.2 Wetland Conservation Statistics

In discussing wetland conservation issues, a number of other simulation outputs were used. The NPV difference per hectare drained discussed in the previous section could be used as a one time incentive payment to farm operators to maintain their wet areas in their natural state. However, enforcement would be an issue with one time payments. For example, if the land was sold to another farm operator after a one time payment was made, how does the organization or individual that made that payment prevent the new farm operator from draining these lands? To avoid this issue, the NPV differences per hectare drained were converted to annuity payments. These would be yearly payments made to farm operators that agreed not to drain their lands during the year the payment was made.

The total area drained by the farm operator and what this represented as a percentage of the farm operator's total wet area provided an indication of the area at risk of being drained. Total area drained was divided into wetland area and cropped basin area. Percentages of wet areas drained were given for both the land in which the farm operator owned and also the total land operated. The percentage of wet area drained was summarized with two figures because it was assumed that farm operators did not drain rented lands. The percentage of wet area owned drained by the farm operator indicated how much of the wet areas on land owned by farm operators was at risk of drainage, whereas the percentage of wet area drained on the total land operated provided an estimate of the remaining wet area on the farm.

5.3.4.3 Other Summary Statistics

Statistics relating to nuisance costs were also summarized. This was performed because few research studies incorporated nuisance costs into the analysis. Nuisance cost outputs were summarized for machinery costs and input waste in the initial year of the analysis (before drainage was conducted) as a total value for the entire farm operation and as a percentage of total variable cost (input and machinery operating expenses). Reporting these values pertaining to nuisance costs provided an indication of their effect on variable costs. They could also be used for comparison with other research conducted pertaining to nuisance costs.

5.4 Chapter Summary

The empirical simulation model developed to analyze the economics of wetland drainage in the RM of Emerald was a stochastic dynamic model. It utilized a representative farm from the study area and the analysis was conducted over a 20-year period. Outputs of the analysis indicated whether it was in the best interest of the farm operator to expand their cultivated land base through drainage, provided insight into the amount of wetland area potentially at risk of drainage, and allowed for estimation of incentive payments that farm operators may accept to maintain wetland resources.

The representative farm used in the analysis was a typical farm from the RM of Emerald. It was comprised of actual quarter sections from the study area. Farm size was allowed to vary to represent the different farm sizes within the study area. Machinery complements were chosen for no-till tillage systems that were common in the RM of Emerald and crop rotations used by these farms consisted of crops predominantly grown in the area.

The simulation model included weather, crop yields, commodity prices and the time a farm operator had available to devote to drainage projects as stochastic variables. These variables were estimated using appropriate data for the study area. The stochastic variables affected the revenues and costs used to calculate the performance of the farm over the 20-year period, and they also affected the farm operator's drainage decisions.

Drainage was modeled to represent the type of drainage utilized in the RM of Emerald. These were projects conducted by the farm operator using their own equipment. Benefit and cost streams were identified for draining lands and used in the farm operator's drainage decision process as well as determining whether drainage improved the performance of a farm relative to maintaining it's existing cultivated land base.

Flexibility of the model enabled scrutiny of several factors that could potentially impact the economic feasibility drainage. Nine scenarios were utilized in the analysis that included: (1) the economics of purchasing a scraper to perform drainage, (2) the economics of renting a scraper to perform drainage, (3) the economics of conducting additional drainage, (4) the economics of only draining wetlands, (5)the impact of farm size on economic feasibility, (6) the impact of nuisance factors on economic feasibility, (7) the impact of farm programs on drainage, (8) the impact of fixed initial land base allocations, and (9) a historical analysis of drainage. Seven sensitivity analyses were also conducted. The variables chosen for sensitivity analysis were: (1) the number of years to complete a drainage project, (2) drainage costs, (3) the frequency of crop losses in cropped basins, (4) drained area yields relative to upland yields, (5) crop rotation, (6) commodity prices, and (7) the discount rate.

In the analysis, the economic feasibility of drainage was determined through the use of net present values of cash flows, non-discounted cash flows and present values of drainage costs. Model outputs with policy implications included estimates of incentive payments and wet areas lost through drainage. Variables related to nuisance costs were also summarized as outputs since few researchers have incorporated them into their analyses.

Chapter 6: Results and Discussion

In this chapter the simulation results for the scenarios and sensitivity analyses outlined in Chapter 5 are presented along with a discussion of key findings. Tables of all the summary statistics are presented in Appendix L, since only those outputs deemed most relevant to each analysis are included within this chapter. It is important to note that differences in NPVs discussed in this chapter were calculated for two alternative actions, one in which the farm operator did not perform drainage and the other where the farm operator used drainage as a means to expand their cultivated land base. The differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage.

6.1 Basic Scenarios

6.1.1 Scenario 1 – The Economics of Purchasing a Scraper to Perform Drainage

In this scenario, it was assumed that the farm operator purchased a scraper to perform drainage and drained those lands that appeared economically feasible to drain. The decision to conduct drainage was compared to an alternative action where the farm operator did not drain land. Detailed results for this scenario are provided in Table L.1 in Appendix L.

Over the course of the simulation, the farm operator drained, on average, a total of 28.74 hectares of land (24.09 hectares wetlands and 4.65 hectares of cropped basins) representing 48% of the wet area on the farm operator's own land and 36% of the wet area on the total land operated (Table 6.1). On average, it took the farm operator 3.11 years to complete drainage on a quarter section. Projects would take longer than three years to complete if the crop matured late because of poor weather during the growing season and/or if weather in the fall did not cooperate and few workdays were available to perform field operations. Also, nuisance costs for this farm before drainage was conducted totaled approximately $2,000/year representing 2.51% of total variable costs. Drainage would reduce these costs and provide the farm operator with more time to devote to field operations during the growing season.

The results suggest that purchasing a scraper was not economically feasible (Table 6.1). When the farm performed drainage, the NPV on a perpetuity basis was $5,404 lower than if the farm did not conduct drainage. Each hectare drained reduced the NPV of the farm relative to not performing drainage by, on average, $384. Furthermore, the NPV was higher in only 22% of iterations. These negative results were caused by the impact of purchasing a scraper on cash flow. Figure 6.1 reveals a large negative mean difference in cash flow in year one for when the farm operator purchased a scraper. Due to discounting, the large negative mean difference at the beginning of the simulation resulted in an overall negative mean NPV. However, the mean NPV difference was less than the capital cost of a scraper used for this size of farm ($16,883). Therefore, drainage could potentially be advantageous for a farm operator who is able to obtain a scraper at a lower cost. For example, a farm operator could purchase a used scraper or perhaps share a scraper with a neighboring farm operator interested in draining land.

Table 6.1 – Means and standard deviations of means for a representative farm that conducted drainage with a purchased scraper relative to performing no drainage

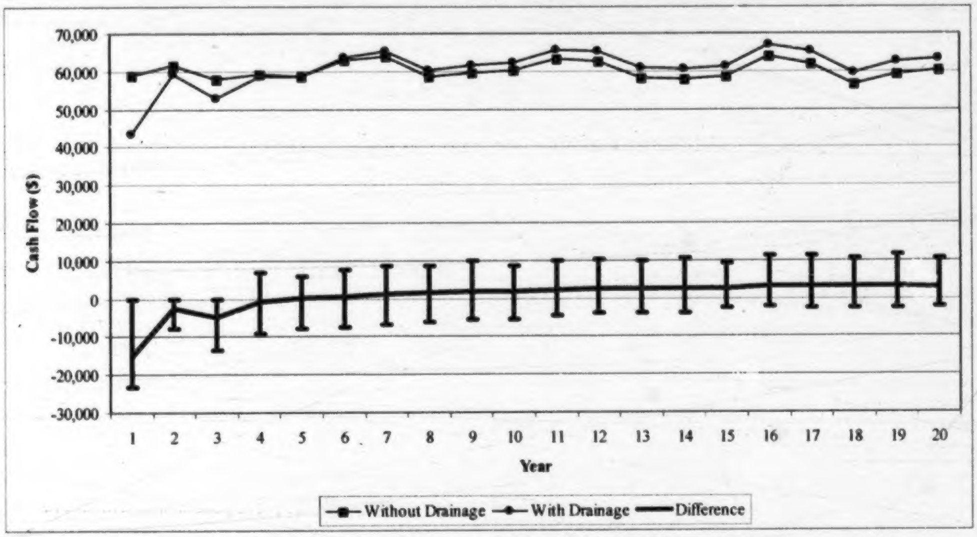
Variable	Mean	Std Dev
Wetlands Drained (ha)	24.09	20.03
Cropped Basins Drained (ha)	4.65	5.23
Percent of Wet Area Drained on Owned Land	48.07%	26.22%
Percent of Wet Area Drained on Total Land Operated	36.42%	20.27%
Number Years to Drain a Quarter Section	3.11	0.23
Initial Machinery Nuisance Cost Total for Farm[a]	$1,590	$75
Initial Input Waste Nuisance Cost Total for Farm[a]	$536	$22
Initial Nuisance Costs as a percentage of Total Variable Costs[a]	2.51%	0.08%
Perpetuity NPV Difference[b]	-$5,404	$11,677
Perpetuity NPV Difference per Hectare Drained[b]	-$384	$693
Percentage of Iterations where Perpetuity NPV was Positive	22.00%	
PV of Cost of Drainage Conducted[c]	$482	$214

Notes: [a] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value.

However, standard deviations in Table 6.1 for NPV variables were large relative to the averages and confidence intervals for non-discounted cash flows shown in Figure 6.1 were wide relative to average differences. This was caused by changing the quarter sections for each iteration and revealed the impact that the characteristics of the quarter sections comprising a farm had on the results. Therefore, even though drainage did not appear to be economically feasible on average in this scenario, returns to drainage could be significantly positive if a particular farm was comprised of quarter sections where the costs to drain were sufficiently low and/or the benefits from drainage were high.

Mean non-discounted cash flows shown in Figure 6.1 indicate that whether performing drainage or not the farm had relatively similar cash flows. On average, cash flows when the farm conducted drainage became greater than when it did not in year five of the simulation. Improved cash flows were the result of additional crop returns from cultivated hectares gained through drainage. The confidence interval for the difference in cash flows always included zero suggesting that the differences in cash flows were not statistically significant. However, over the course of the simulation the 5% confidence level became closer to zero. Peaks and valleys in Figure 6.1 were caused by the crop rotation. Canola returns per hectare were higher, on average, than other crops; therefore cash flow was higher during years when more canola was grown.

Figure 6.1 – Cash flows and differences in cash flows over 20 years for a representative farm that conducted drainage with a purchased scraper relative to performing no drainage



Note: The vertical bars on cash flow difference represent the 90% confidence interval around the mean.

The present value of the cost of draining one hectare of land was $482, on avearge (Table 6.1). This was less than the mean cost of purchasing land in the RM of Emerald ($640/ha). This indicated that expanding one's land base through drainage warrants careful economic consideration, although in this scenario it does not appear to be in the farm operator's best interests.

6.1.2 Scenario 2 – The Economics of Renting a Scraper to Perform Drainage

The second scenario considered renting rather than purchasing a scraper. This was considered at least in part since drainage did not appear economically feasible if a scraper was purchased. Renting a scraper did not involve the large initial cash outlay that purchasing did and therefore may be an attractive alternative for those contemplating drainage projects. However, the variable costs per hour for a rented scraper were greater than those for a scraper a farm operator owned[45]. Detailed results for this scenario are provided in Appendix L in Table L.3.

Over the course of the simulation, the farm operator drained, on average, a total of 15.74 hectares of land (13.09 hectares wetlands and 2.65 hectares of cropped basins) representing 26% of the wet area on the farm operator's land and 20% of the wet area on the total land operated (Table 6.2). The mean area drained was lower than in Scenario 1 since variable costs per hour were higher for rented drainage equipment. On average, it took the farm operator 3.01 years to complete drainage on a quarter section. Projects would take longer than three years to complete if the crop matured late because of poor weather during the growing season and/or if weather in the fall did not cooperate and few workdays were available to perform field operations. The average time to complete drainage on a quarter section was lower than in Scenario 1 because it was assumed that the farm operator drained quarter sections with the highest NPVs first. These projects often required the construction of few drainage ditches and therefore took less time to complete. Total initial nuisance costs for this farm were the same as Scenario 1 since the farm assumptions were the same.

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[45] Operating costs for a rented versus owned scraper are shown in Table 5.20.

In this scenario, simulation results indicated that renting a scraper was economically feasible. When the farm conducted drainage, the mean NPV was $5,300 greater than when it did not conduct drainage. On average, each hectare of drained land improved the performance of the farm by $280 relative to not draining land. The NPV of the farm was also higher in 61% of iterations when drainage was conducted.

Table 6.2 – Means and standard deviations of means for a representative farm that rented a scraper to conduct drainage relative to performing no drainage

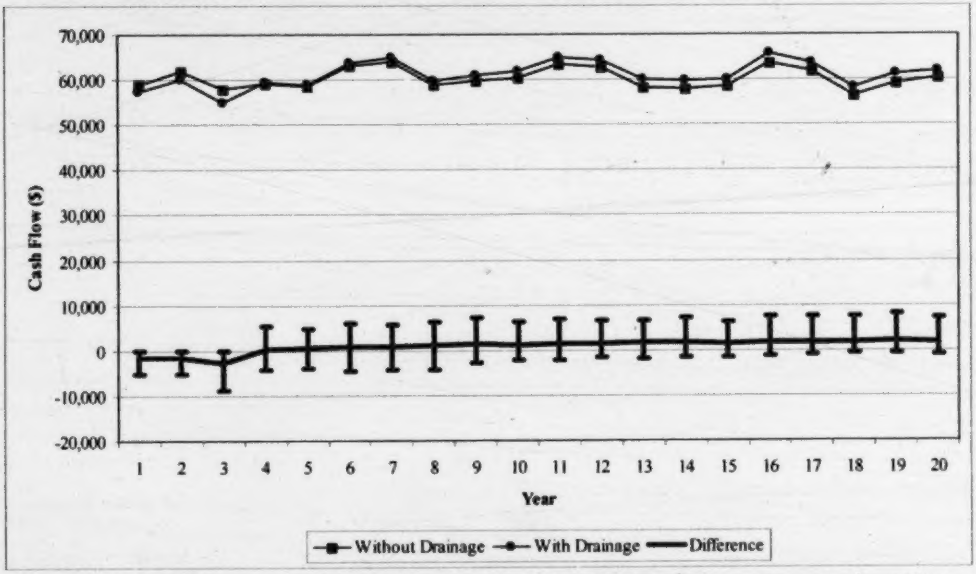
Variable	Mean	Std Dev
Wetlands Drained (ha)	13.09	14.87
Cropped Basins Drained (ha)	2.65	4.15
Percent of Wet Area Drained on Owned Land	26.43%	21.26%
Percent of Wet Area Drained on Total Land Operated	20.05%	16.43%
Number Years to Drain a Quarter Section	3.01	0.08
Initial Machinery Nuisance Cost Total for Farm[a]	$1,590	$75
Initial Input Waste Nuisance Cost Total for Farm[a]	$536	$22
Initial Nuisance Costs as a percentage of Total Variable Costs[a]	2.51%	0.08%
Perpetuity NPV Difference[b]	$5,300	$9,376
Perpetuity NPV Difference per Hectare Drained[b]	$280	$431
Percentage of Iterations where Perpetuity NPV was Positive	61.00%	
PV of Cost of Drainage Conducted[c]	$427	$291

Notes: [a] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value.

On the other hand, standard deviations of NPV variables in Table 6.2 were large relative to the averages and confidence intervals for non-discounted cash flows shown in Figure 6.2 were wide relative to average differences. This was caused by changing the quarter sections for each iteration and revealed the impact that the characteristics the quarter sections comprising a farm had on the results. Therefore, even though drainage does appear to be economically feasible on average in this scenario, returns to drainage could be negative if NPVs for the individual quarter sections were marginally positive and actual yields and prices experienced by the farm generated returns per hectare that were lower than those the farm operator used when determining which quarter sections to drain.

Mean non-discounted cash flows shown in Figure 6.2 indicate that whether performing drainage or not the farm had relatively similar cash flows. When conducting drainage the farm had mean cash flows slightly less than when it did not invest in drainage until year four when they became slightly larger. Improved cash flows were the result of additional crop returns from cultivated hectares gained through drainage. The confidence interval for the difference in mean cash flows always included zero suggesting that the differences in cash flows were not statistically significant. However, over the course of the simulation the 5% confidence level became closer to zero. Peaks and valleys in Figure 6.2 were caused by the crop rotation. Canola returns per hectare were higher, on average, than other crops; therefore cash flow was higher during years when more canola was grown.

Figure 6.2 – Cash flows and differences in cash flows over 20 years for a representative farm that rented a scraper to conduct drainage relative to performing no drainage



Note: The vertical bars on cash flow difference represent the 90% confidence interval around the mean.

The present value of the cost of draining one hectare of land was $427, on average. This cost was less than the mean cost of purchasing land in the study area ($640/ha) and also less than the cost from Scenario 1. This occurred because it was assumed that the farm operator drained quarter sections with the highest NPVs first and these often had lower costs per hectare drained. Since the farm operator drained, on average, less land in this scenario, the present value of mean costs per hectare drained was lower. The lower cost of acquiring land through drainage relative to purchasing land indicated that expanding one's land base through drainage warrants careful economic consideration. However, if a farm operator decided to expand their cultivated land base, purchasing land allows the farm operator to realize returns from additional cultivated hectares immediately, whereas it takes at least three years before benefits from drainage are realized.

6.1.3 Scenario 3 – The Economics of Conducting Additional Drainage

This scenario investigated the economic feasibility of drainage when a farm operator already owned a scraper and was considering additional drainage projects. Here the farm operator was deciding between undertaking new drainage projects where drainage appeared economically feasible and simply maintaining the existing drainage infrastructure on their land. Detailed results for this scenario are provided in Appendix L in Table L.4.

Over the course of the simulation, the farm operator drained, on average, a total of 28.51 hectares of land (23.91 hectares wetlands and 4.60 hectares of cropped basins) representing 48% of the wet area on the farm operator's land and 36% of the wet area on the total land operated (Table 6.3). The farm operator drained slightly less land in this scenario than in Scenario 1 because it took, on average, slightly longer (0.08 years) to drain a quarter section. It took longer to complete drainage projects because the farm operator had less time to devote to new drainage projects due to time spent maintaining existing ditches. Total initial nuisance costs for this farm were the same as Scenario 1 since the farm assumptions were the same.

Table 6.3 – Means and standard deviations of means for a representative farm that owned a scraper and conducted additional drainage relative to performing no additional drainage

Variable	Mean	Std Dev
Wetlands Drained (ha)	23.91	20.33
Cropped Basins Drained (ha)	4.60	5.15
Percent of Wet Area Drained on Owned Land	47.70%	25.99%
Percent of Wet Area Drained on Total Land Operated	36.13%	20.10%
Number Years to Drain a Quarter Section	3.19	0.34
Initial Machinery Nuisance Cost Total for Farm[a]	$1,590	$75
Initial Input Waste Nuisance Cost Total for Farm[a]	$536	$22
Initial Nuisance Costs as a percentage of Total Variable Costs[a]	2.51%	0.08%
Perpetuity NPV Difference[b]	$9,389	$12,197
Perpetuity NPV Difference per Hectare Drained[b]	$314	$373
Percentage of Iterations where Perpetuity NPV was Positive	76.80%	
PV of Cost of Drainage Conducted[c]	$475	$210

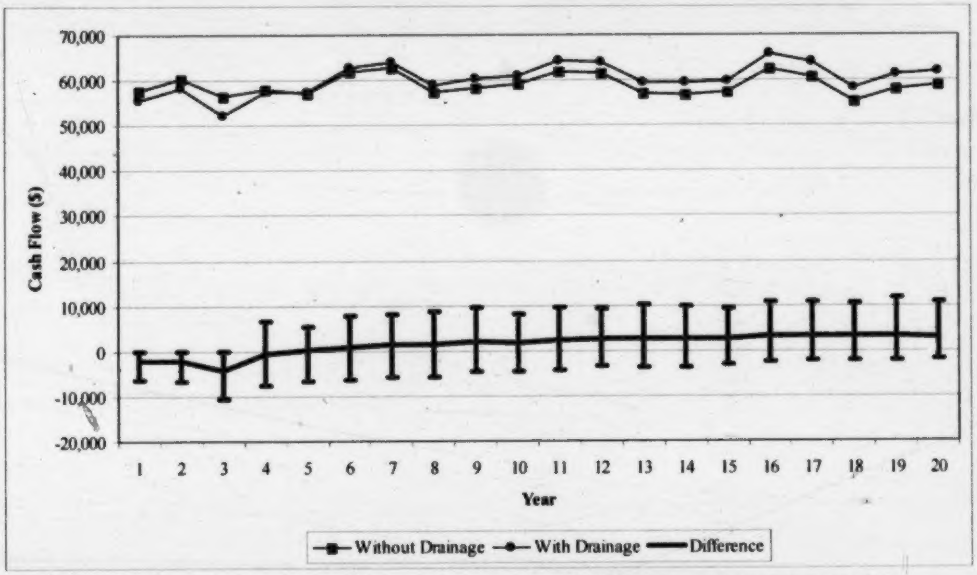
Notes: [a] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value.

As in the scenario where the farm operator rented a scraper, the outputs suggest that conducting additional drainage was in the farm operator's best interest. The farm that conducted drainage had a mean NPV $9,389 greater than the farm that did not conduct drainage. On average, each hectare of drained land improved the performance of the farm by $314 relative to not draining land. The NPV for the farm when it performed drainage was higher in 77% of iterations.

It is important to note that the standard deviations of NPV variables in Table 6.3 were large relative to the averages and confidence intervals for non-discounted cash flows shown in Figure 6.3 were wide relative to average differences. This was caused by changing the quarter sections for each iteration and revealed the impact that the characteristics of the quarter sections had on the results. Therefore, even though drainage did appear to be economically feasible, on average, in this scenario, returns to drainage could be negative if NPVs for the individual quarter sections were marginally positive and actual yields and prices experienced by the farm generated returns per hectare that were lower than those the farm operator used when determining which quarter sections to drain.

Mean non-discounted cash flows shown in Figure 6.3 reveal that the farm had relatively similar mean cash flows when conducting additional drainage and simply maintaining existing drainage infrastructure. When conducting additional drainage, the farm had mean cash flows slightly less than when it simply maintained existing drainage infrastructure until year four when they became slightly larger. The confidence interval for the difference in cash flows always included zero suggesting that the differences in cash flows were not statistically significant. However, over the course of the simulation the 5% confidence level became closer to zero. Peaks and valleys in Figure 6.3 were

Figure 6.3 – Cash flows and differences in cash flows over 20 years for a representative farm that owned a scraper and conducted additional drainage relative to performing no additional drainage



Note: The vertical bars on cash flow difference represent the 90% confidence interval around the mean.

caused by the crop rotation. Canola returns per hectare were higher, on average, than other crops; therefore cash flow was higher during years when more canola was grown.

The present value of the cost of draining one hectare of land was $475, on average. This was less than the mean cost of purchasing land in the study area ($640/ha) and less than the cost from Scenario 1. This occurred because it was assumed that the farm operator drained the quarter sections with the highest NPVs first and these often had lower costs per hectare drained. Therefore, since less land was drained in this scenario, the present value of mean costs per hectare drained was lower. Given that the cost of acquiring land through drainage was lower than purchasing land, expanding one's land base through drainage warrants careful economic consideration. However, if a farm operator decides to expand their cultivated land base, purchasing land allows the farm operator to realize returns from additional cultivated hectares immediately, whereas it takes at least three years before benefits from drainage are realized.

6.1.4 Summary and Comparison of Scenarios 1 Through 3

Scenarios one through three represent the main scenarios that analyzed the economic feasibility of drainage for a representative farm in the RM of Emerald. Additional summaries of findings are presented here that compared results across the three scenarios. Detailed results for the scenarios in this comparison are provided in Tables L.1, L.3 and L.4 in Appendix L.

The main summary statistics for these three scenarios are shown in Table 6.4. The outputs indicated that the farm operators in both Scenario 1 and 3 drained about the same amount of land (28.74 ha versus 28.51 ha). This was to be expected since both scenarios used exactly the same variable costs for conducting drainage. The only difference was that the farm operator in Scenario 3 was maintaining existing drainage ditches. The time the farm operator must commit to maintaining existing ditches resulted in slightly less drainage conducted, on average, during the simulation period for Scenario 3 versus Scenario 1. The representative farm that rented a scraper conducted, on average, about half as much drainage as representative farms in the other scenarios (15.74 ha).

The summaries for NPV variables revealed that, as anticipated, farm operators conducting additional drainage (Scenario 3) rather than initiating drainage (Scenarios 1 and 2) performed the best out of the three scenarios examined. However, in Scenario 2 where the farm operator rented a scraper, the farm performed nearly as well on a per hectare drained basis ($280/ha versus $314/ha). The mean cost of land in the RM of Emerald was $640/ha. Since present values of costs per hectare drained were, on average, all lower than this value, expanding one's land base through drainage would appear to be a rational decision.

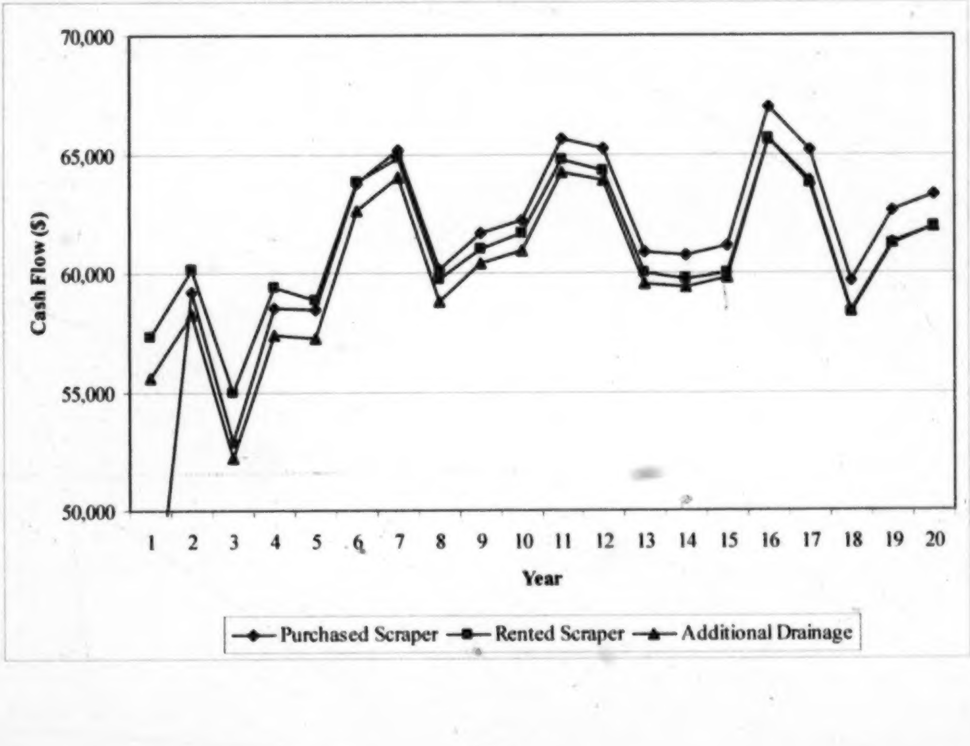
Cash flows of the three farms that conducted drainage are shown in Figure 6.4. Initially, the representative farm that rented a scraper had the highest mean level of cash flow, followed by the representative farm that was conducting additional drainage and then the representative farm that purchased a scraper. This occurred because renting a scraper did not involve the initial cash outlay that purchasing a scraper did and the farm operator did not have the costs associated with performing maintenance on previously completed drainage projects. By year 20, the representative farm that purchased a scraper in order to perform drainage had the highest mean level of cash flow, followed by the representative farm conducting additional drainage and the representative that rented a

Table 6.4 – Means of selected summary statistics for Scenarios 1 through 3

Variable	Scenario 1: Purchasing a Scraper	Scenario 2: Renting a Scraper	Scenario 3: Additional Drainage
Wetlands Drained (ha)	24.09	13.09	23.91
Cropped Basins Drained (ha)	4.65	2.65	4.60
Percent of Wet Area Drained on Owned Land	48.07%	26.43%	47.70%
Percent of Wet Area Drained on Total Land Operated	36.42%	20.05%	36.13%
Perpetuity NPV Difference[a]	-$5,404	$5,300	$9,389
Perpetuity NPV Difference per Hectare Drained[a]	-$384	$280	$314
Percentage of Iterations where Perpetuity NPV was Positive	22.00%	61.00%	76.80%
PV of Cost of Drainage Conducted[b]	$482	$427	$475

Notes: [a] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [b] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage.

Figure 6.4 – Comparison of mean cash flows for Scenarios 1 through 3



scraper. The farm that purchased a scraper conducted the most drainage and therefore had the largest cultivated land base by year 20, which resulted in the highest mean level of cash flows. Mean differences in cash flow between the representative farm that conducted additional drainage and the representative farm that rented a scraper were minimal (<$1,000) from year 7 through 20.

6.1.5 Scenario 4 – The Economics of Only Draining Wetlands

In this scenario, it was assumed that the farm operator only drained the wetlands on their land. The results are compared to Scenario 1 where the farm operator was required to purchase a scraper and drained both wetlands and cropped basins. Detailed results for this scenario are provided in Appendix L in Tables L.1 and L.5.

Comparing the results for the two cases revealed that the farm operator drained, on average, more wet area in total (29.28 ha versus 28.74 ha) when draining solely wetlands (Table 6.5). Both strategies were associated with negative returns and were equally unattractive as an alternative to draining no wet areas whatsoever. It did not appear that assuming farm operators drained both wetlands and cropped basins would have a large impact on the results. For the case where the farm operator drained only wetlands,

Table 6.5 – Means and standard deviation for a representative farm that purchased a scraper to conduct drainage relative to performing no drainage and drained only wetlands versus draining both wetlands and cropped basins

	Area Drained Scenario				
	Wetlands Only		Wetlands and Cropped Basins		
Variable	Mean	Std Dev	Mean	Std Dev	% Change in Mean[a]
Wetlands Drained (ha)	29.28	19.68	24.09	20.03	21.55%
Cropped Basins Drained (ha)	0.00	0.00	4.65	5.23	-100.00%
Percent of Wet Area Drained on Owned Land	59.63%	25.34%	48.07%	26.22%	24.04%
Percent of Wet Area Drained on Total Land Operated	45.28%	20.14%	36.42%	20.27%	24.34%
Perpetuity NPV Difference[b]	-$5,565	$12,425	-$5,404	$11,677	-2.99%
Perpetuity NPV Difference per Hectare Drained[b]	-$468	$1,175	-$384	$693	-21.79%
Percentage of Iterations where Perpetuity NPV was Positive	26.30%		22.00%		19.55%
PV of Cost of Drainage Conducted[c]	$604	$221	$482	$214	25.20%

Notes: [a] Percent changes in means are calculated for the case where the farm operator drained wetlands and cropped basins. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value.

however, both calculated mean NPV differences were lower. The mean NPV difference between the two scenarios was only marginally lower, whereas the mean NPV difference per hectare drained dropped by 22%. Fewer hectares were likely drained in iterations where crop yields and/or commodity prices were poor in the case where only wetlands were drained relative to the situation where both wetlands and cropped hectares. This would result in significantly larger negative NPV values per hectare drained since the initial cash outlay for purchasing a scraper was included in these calculations.

On the other hand, draining solely wetlands generated positive NPVs more often than the case for draining both wetlands and cropped basins (Table 6.5). This was probably caused by the relationship between precipitation and the frequency of crop losses in cropped basins. In years of normal precipitation, cropped basins produce crops and therefore draining them provides no additional benefit.

The standard deviations for NPV outputs for the case where the farm operator drained both wetlands and cropped basins were narrower. The standard deviations for the NPV outputs were likely wider for the farm draining only wetlands because this farm operator engaged in more expensive drainage projects (i.e. the PV of drainage costs was, on average, $604 versus $482). More expensive drainage projects involve a greater level of risk. Returns to these projects are higher under favorable conditions and lower in unfavorable conditions.

6.1.6 Scenario 5 – The Impact of Farm Size on Economic Feasibility

Since different sized farms had different machinery complements and therefore different cost structures, it is likely that they would have different returns to drainage. Five farm sizes were utilized in this scenario: 4, 8, 12, 16 and 20 quarter sections. Separate simulations were performed for purchasing a scraper and conducting additional drainage for each farm size. Farms that purchased a scraper were assumed to have performed no previous drainage on their land, whereas farms conducting additional drainage were assumed to already own a scraper and to have conducted drainage in the past. Detailed results for this scenario are provided in Tables L.1, L.4 and Tables L.6 through L.13 in Appendix L.

The results revealed that as farm size increased from 4 to 20 quarter sections, more drainage was conducted (Table 6.6). This was expected since larger farms had more wetland area. As the farm size was increased for the case where the farm operator purchased a scraper, the percentage of land drained also increased from 47% to 56% for the percent of wet area drained on land owned by the farm operator and from 35% to 42% for the total land operated. This occurred because it was assumed that it would be more costly to maneuver larger machinery possessed by larger farms around wetland obstacles. However, contrary to findings for farms that conducted drainage through purchasing a scraper, the percentages of wet area drained did not continue to increase along with farm size for farms that were conducting additional drainage. These percentages decreased for farm sizes of 16 and 20 quarter sections. Time required maintaining existing drainage ditches caused this outcome. Farms that purchased scrapers to conduct drainage were assumed to not have any existing drainage ditches on their land. Therefore, time was not as much of a limiting factor. Larger farms also had more stringent time constraints and less time remaining in the fall in order to perform drainage. By assumption the farm operator expected to complete drainage on a particular quarter

Table 6.6 – Means of summary outputs by farm size for representative farms that purchased a scraper to conduct drainage relative to performing no drainage and representative farms that already owned a scraper and conducted additional drainage relative to performing no additional drainage

Purchased Scraper	Number of Quarter Sections				
Variable	4	8	12	16	20
Yearly Revenue - No Drainage	$68,555	$137,195	$205,749	$274,320	$342,795
Wetlands Drained (ha)	11.87	24.09	40.20	54.58	68.64
Cropped Basins Drained (ha)	2.28	4.65	7.68	10.26	13.06
Percent of Wet Area Drained on Owned Land	46.82%	48.07%	54.22%	55.35%	56.01%
Percent of Wet Area Drained on Total Land Operated	35.22%	36.42%	40.81%	41.63%	41.99%
Number Years to Drain a Quarter Section	3.01	3.11	3.12	3.21	3.32
Perpetuity NPV Difference[a]	-$7,343	-$5,404	-$6,314	$583	$10,118
Perpetuity NPV Difference per Hectare Drained[a]	-$626	-$384	-$318	-$117	$54
Percentage of Iterations where Perpetuity NPV was Positive	9.00%	22.00%	28.70%	42.60%	60.40%
PV of Cost of Drainage Conducted[b]	$413	$482	$529	$533	$522

Additional Drainage	Number of Quarter Sections				
Variable	4	8	12	16	20
Yearly Revenue - No Drainage	$68,555	$137,195	$205,749	$274,320	$342,795
Wetlands Drained (ha)	11.85	23.91	39.43	51.84	62.10
Cropped Basins Drained (ha)	2.28	4.60	7.48	9.65	11.83
Percent of Wet Area Drained on Owned Land	46.75%	47.70%	53.13%	52.47%	50.66%
Percent of Wet Area Drained on Total Land Operated	35.17%	36.13%	39.98%	39.46%	37.98%
Number Years to Drain a Quarter Section	3.02	3.19	3.32	3.75	4.30
Perpetuity NPV Difference[a]	$4,309	$9,389	$16,271	$22,406	$28,318
Perpetuity NPV Difference per Hectare Drained[a]	$256	$314	$329	$353	$375
Percentage of Iterations where Perpetuity NPV was Positive	58.20%	76.80%	86.00%	92.20%	96.30%
PV of Cost of Drainage Conducted[b]	$412	$475	$507	$477	$423

Notes: [a] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [b] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage.

section in three years. However, for the case where the farm operator was conducting additional drainage, the mean actual time it took a farm operator with 20 quarter sections to complete a project during the simulation was 4.30 years. All other farm sizes completed a drainage project in, on average, much less than 4 years.

Table 6.6 also indicates that larger farms experienced greater returns to drainage. For cases where a farm operator purchased a scraper, the results suggest that conducting drainage was only economically feasible for farms operating about 20 quarter sections or more. For farms conducting additional drainage, Table 6.6 indicates that mean NPVs were always positive. As farm size increased from 4 to 20 quarter sections, the value of a drained hectare of land increased from $256/ha to $375/ha. The percentage of iterations where positive differences in NPVs resulted jumped from 58% to 96% as well, which indicated that drainage was also less risky for larger farms.

Present values of the costs of drainage conducted were, on average, lower than the cost of purchasing land in the study area. Therefore, expanding one's land base through drainage warrants careful economic consideration. However, if a farm operator decides to expand their cultivated land base, purchasing land allows the farm operator to realize returns from additional cultivated hectares immediately, whereas it takes at least 3 years before benefits from drainage are realized.

The analysis of farm size facilitated a comparison of incentive payments that could be offered to maintain wetlands in their natural state. The use of incentive payments for wetland conservation are, however, only one of a number of policy instruments that could be used for wetland protection. A simple annuity formula was used to estimate mean annual incentive payments from the value of a drained hectare of land (Table 6.7). These incentive payments could be offered to farm operators to conserve wetlands in the study area. They were calculated on a per hectare of wetlands drained and per hectare of wetlands owned basis. The payments estimated would be made on wetland hectares on land the farm operator owns and not on the total hectares operated.

Table 6.7 – Mean estimates of annual incentives payments for wetland conservation per hectare of wetlands drained and per hectare of wetlands owned by farm size

	Per Hectare of Wetlands Drained		Per Hectare of Wetlands Owned[a]	
Number of Quarter Sections	Purchased Scraper	Additional Drainage	Purchased Scraper	Additional Drainage
4	$0[b]	$25.63	$0	$11.98
8	$0	$31.41	$0	$14.98
12	$0	$32.94	$0	$17.50
16	$0	$35.30	$0	$18.52
20	$5.41	$37.55	$3.03	$19.02

Note: [a] Incentive payments per hectare of wetlands owned were estimated by multiplying the mean per hectare payment by the mean percentage of wet area drained by the farm operator during the simulation. [b] Incentive payments of zero are estimated for situations where it did not appear economically feasible to conduct drainage

Mean payments per hectare of wetlands drained could be used by individuals and organizations targeting specific wetlands for conservation, whereas mean payments per hectare of wetlands owned could be used protect all wetlands on land a farm operator owns. The per hectare drained payments represented the average value of a hectare of land that was economically feasible to drain. The estimated payments per hectare owned were less than the per hectare drained payments since the simulation outputs revealed that, on average, it would not be economically feasible to drain all wet areas on a farm. It is important to recognize that these estimates represent returns to management and fixed inputs over and above the returns for the same farm if it did not conduct drainage to expand its land base since no labour costs or any other fixed costs were deducted in the analysis. Assuming that farm operators have an opportunity cost for their time and labour, these estimates would change. However, it is not possible to state categorically whether the change would be positive or negative. For example, drainage activities require extra labour in the fall, which would increase the economic cost of drainage if considered in the analysis. However, the results of drainage activities also mean more flexibility in time management during critical points in crop production (e.g., seeding, pest control), which would potentially mean a lower cost. The net effect is indeterminate a priori.

Interpretation of Table 6.7 reveals that unless a farm operated approximately 20 quarter sections, it was, on average, not economically feasible to purchase a scraper to begin draining their land. Therefore, in theory no compensation would be necessary to prevent drainage activities on those operations. For these larger farms, the simulation model estimated mean payments of $5.41/year for each hectare drained or $3.03/year for each hectare owned. However, farms could potentially generate positive returns to drainage if they were able to obtain a scraper at a cost less than the capital cost used in the model. A farm operator could purchase a used scraper or share the cost with other farm operators interested in drainage. Therefore, these estimates should be interpreted with caution.

All mean NPVs for those farm operators that already possess the equipment to perform drainage were positive (Table 6.7). Therefore, they would be expected to continue to drain wet areas. Mean payments across the farm sizes remained relatively stable ranging from $25.63/year to $37.55/year for each hectare of wetlands drained and $11.98/year to $19.02/year for each hectare of wetlands owned. Lower machinery costs per hectare and increased nuisance costs were reasons why the payments increased for larger farms. Though not explicitly analyzed, the results of Scenario 2 suggest that mean per hectare payments for farm operators able to rent drainage equipment would be slightly less than findings for farms conducting additional drainage. Scenario 2 also indicated that due to higher variable costs associated with renting a scraper, only about half the area that was drained by those farm operators that own or purchase scrapers can be expected. This implies that mean payments made to an entire farm would be about half of the amounts indicated in Table 6.7 for additional drainage. However, it may not be feasible for larger farms to rent the necessary equipment, given the number of hours that would be required to complete all the economically feasible drainage on their lands.

In Saskatchewan, DUC is currently involved in a pilot project where farm operators in the RM of Emerald are offered incentives in the form of tax credits on wetland hectares on land owned by farm operators (DUC, 2004). Wetland areas that are cropped are not eligible for payments. In exchange, the farm operator agrees not to drain the wetland areas enrolled in the program during the year in which the payment is made (Edwards, 2005). These payments compensate wetland owners for the tax burden associated with wetland ownership. Yearly payments are low, ranging from $1.40-$2.50/ha of wetland enrolled in the program, but they reflect the actual tax paid on wetland areas (Edwards, 2005).

While the per hectare payments estimated in the present study for wetlands owned by the farm operator are not directly comparable to the payments offered under the DUC tax credit program, it is interesting to note the difference in magnitude between the two economic incentives. The comparable direct payments for farm operators conducting additional drainage in the present study were at least four times the amount offered under the tax credit program, whereas payments for farm operators that purchased scrapers prior to conducting drainage were similar. However, participation figures for the program indicate that the program has been quite successful and that farm operators would accept lower compensation payments than those estimated in the simulation. About 39% of wetlands in the RM of Emerald were enrolled in the program in 2004, up from 27% in 2003 (Edwards, 2005). A problem with such a program is that payments are likely made to farm operators that have no intention of draining or for areas that are not economically feasible to drain. However, it is difficult to determine which wetlands are at risk of drainage and which farm operators are contemplating drainage projects.

6.1.7 Scenario 6 – The Impact of Nuisance Factors on Economic Feasibility

In this scenario, the impact of different nuisance cost patterns was estimated. Three cases were considered: the first assumed that it was costless to farm around wetland obstacles, the second assumed that nuisance costs increased at a constant rate as the farm size (machinery complement) and number of wetlands within a quarter section increased, and the third assumed that nuisance costs increased at an increasing rate as the farm size (machinery complement) and the number of wetlands within a quarter section increased. Two farm sizes, 8 and 16 quarter sections were analyzed. Representative farms conducting additional drainage were chosen for analysis in this scenario, since the economic feasibility of drainage for such farms was previously shown to be positive. These farms already possessed the necessary equipment to perform drainage and had conducted drainage in the past. Results were compared to Scenario 3. Detailed results for this scenario are provided in Tables L.4, L.12, and Tables L.14 through L.17 in Appendix L.

Results for this analysis reveal that nuisance costs were an important factor in the drainage decision (Table 6.8). In this scenario, for farms comprised of 8 quarter sections, at least 3.59 ha more land was drained in cases that included an estimate of nuisance costs relative to the case that did not include an estimate of nuisance costs. For 16 quarter sections, at least 7.92 ha more land was drained when an estimate of nuisance costs was included in the simulation. These results indicated that nuisance costs appear to increase the area drained by about 10%-15%. This finding was expected given that reductions in nuisance costs represent additional benefits from drainage.

Nuisance costs for the farm comprised of 8 quarter sections initially totaled $2,126-$2,245 and represented 2.51%-2.65% of total variable costs and initially totaled $4,675-$5,225 for the farm comprised of 16 quarter sections representing 3.02%-3.35% of total variable costs depending on the assumption used for nuisance costs. The wider range for the farm comprised of 16 quarter sections indicated that determining how nuisance costs change as machinery complements increase will be important since machinery is becoming larger.

Nuisance costs appear to represent approximately 35% of the benefits received through drainage. The proportion of benefits that nuisance costs comprised, however, was not explicitly calculated within the model. Therefore, this relationship was determined by subtracting the NPV differences in for scenarios that included estimates of nuisance costs from the scenarios that did not include estimates of nuisance costs and dividing that value by the NPV difference for the scenarios where drainage costs were estimated since. The results are not a perfect estimate of the proportion of benefits attributed to nuisance costs since different amounts of drainage were conducted in each scenario, but they do indicate that nuisance costs represent a significant proportion of benefits received through drainage. Including an estimate for nuisance costs also had implications for estimates of annual incentive payments that could be offered to farm operators to forgo drainage. If it were costless to maneuver around wetland obstacles and no inputs were wasted in doing so, incentive payments per hectare drained would be about $10/ha lower

Table 6.8 – Means of selected summary statistics by farm size for the impact of different nuisance cost assumptions for a farm that owned a scraper and conducted additional drainage relative to performing no additional drainage

	Nuisance Cost Scenario by Farm Size					
	8 Quarter Sections			16 Quarter Sections		
Variable	Increasing[a]	Constant[b]	None[c]	Increasing[a]	Constant[b]	None[c]
Wetlands Drained (ha)	23.91	24.11	21.11	51.84	51.00	44.73
Cropped Basins Drained (ha)	4.60	4.65	3.82	9.65	9.43	7.78
Percent of Wet Areas Drained on Owned Land	47.70%	48.15%	41.43%	52.47%	51.56%	44.65%
Percent of Wet Areas Drained on Total Land Operated	36.13%	36.47%	31.44%	39.46%	38.78%	33.63%
Initial Machinery Nuisance Cost Total for Farm[d]	$1,590	$1,679	$0	$3,645	$3,261	$0
Initial Input Waste Nuisance Cost Total for Farm[d]	$536	$566	$0	$1,580	$1,413	$0
Initial Nuisance Costs as a percentage of Total Variable Costs[d]	2.51%	2.65%	0.00%	3.35%	3.02%	0.00%
Perpetuity NPV Difference[e]	$9,389	$9,506	$6,093	$22,406	$21,496	$14,216
Annual Incentive Payment ($/ha drained)	$31	$32	$22	$35	$34	$25

Notes: [a] Increasing represents a scenario whereby nuisance costs increase at an increasing rate as the number of wetlands within a quarter section increase. [b] Constant represents a scenario whereby the rate of nuisance costs increases at a constant rate as the number of wetlands within a quarter section increase. [c] None represents a scenario where nuisance costs were assumed to be zero. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted. [e] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage.

Comparing the results of this scenario to previous findings was somewhat difficult. However, the results provided in this scenario were compared to two other studies where nuisance cost estimates were provided, Accutrak Systems (1991) and Wanchuck (1986).

The Desjardins (1983) study was used to estimate the nuisance costs used in this analysis; therefore it is excluded from this comparison.

Wanchuk (1986) reported findings for cost savings for machinery and input costs resulting from surface drainage projects. These savings averaged $157/year/farm with a range of $0-$972/year/farm and $130/year/farm with a range of $0-$865/year/farm for machinery and input costs, respectively. The farms analyzed in Wanchuk's study were slightly different from those considered in the current study, in that they were smaller and there were significant hectares of forage crops and pasture on these farms. Updating Wanchuk's results from 1986 dollars to 2003 dollars using the CPI index provided a range of $0-$1,522 for machinery costs and $0-$1,355 for input costs. Table 6.8 shows that a farm with 8 quarter sections of land incurred, on average, $2,126 dollars annually in nuisance costs, $1,590 attributed to additional machinery costs and $536 in input waste prior to draining any lands under the "increasing" nuisance cost assumption. The machinery cost estimate was just outside of the range from Wanchuk (1986), whereas the input waste estimate fell well within the range from Wanchuk (1986).

It should be noted that Wanchuck (1986) provided estimates of cost savings resulting from the drainage projects analyzed in the study suggesting that total nuisance costs per farm would be higher if other wetlands existed on these farms. Also, several of the drainage projects conducted in the Wanchuk (1986) study were on rangeland where variable costs would be lower. Comparing results for the present analysis to those of Wanchuk (1986) indicated that estimates of nuisance costs appear representative of what would be experienced on a typical farm.

The results of the current study were also compared with those from the Accutrak Systems (1991) study. In order to do so, cost assumptions for machinery and input costs of the Accutrak Systems (1991) study were updated with those used in this research. This resulted in an increase in the nuisance costs of a typical wetland analyzed by Accutrak Systems (1991) from $24/year to $60/year. The updated value was more than double the original value because of differences in rotations and input costs used. A two-year rotation was used in the Accutrak Systems (1991) study, whereas a five-year rotation was used in the present research.

Loosely using the Accutrak Systems (1991) conclusion that nuisance costs were relatively invariant to the size of the wetland, each wetland obstacle would result in additional costs of $60/year. Therefore, quarter sections with 1, 6, and 13 wetlands in them would result in additional costs of $60, $360 and $780, respectively. For a farm comprised of 8 quarter sections of in the present study, about $250, $265, and $425 in additional costs are incurred on quarter sections with 1, 6, and 13 wetlands in them, respectively. Thirteen wetlands were chosen as a comparison figure since the maximum number of wetlands in a quarter section used in the simulation was 13. In the present research, quarter sections with fewer wetlands had higher nuisance costs than what would be estimated using the results of the Accutrak Systems (1991) study, whereas quarter sections with greater wetland numbers had lower nuisance costs than estimates provided by the results of the Accutrak Systems (1992) study. Given that over 90% of quarter sections had fewer than four wetlands, utilizing the findings from the Accutrak Systems (1991) study would provide lower estimates for the impact of nuisance costs.

6.1.8 Scenario 7 – Impact of Farm Programs on Drainage

Indirect subsidies such as CAIS and crop insurance alter the returns and risk associated with farming. These differences in returns could potentially provide further incentives to drain lands. This possibility is investigated in this scenario. Two cases are analyzed, one in which the farm operator participated in both CAIS and crop insurance and the other where the farm operator only participated in crop insurance. Only the CAIS program was analyzed because it was noted during model testing that the CAIS program appeared to significantly increase NPV values for the representative farm, whereas crop insurance did not. In this scenario, it was assumed that the farm operator was contemplating additional drainage, meaning the farm operator already possessed a scraper and was maintaining drainage ditches on completed projects. Detailed results for this scenario are provided in Tables L.4 and L.18 in Appendix L.

The outputs in Table 6.9 pertaining to drained area increased by, on average, 5% when the farm participated in the CAIS program. Total hectares drained increased from 27.12 ha when the farm operator did not participate in the CAIS program to 28.51ha when it did, an increase of just less than 1.5 ha. At the individual farm level, an increase in area drained of 1.5 ha may seem insignificant. However, on a larger geographical scale (e.g. watershed, rural municipality), these "losses" in wetlands could become quite large. For example, if all 202 farms in the RM of Emerald were identical to the one used in this scenario and if all of them participated in the CAIS program, an additional 303 ha of land, on average, would be drained.

Table 6.9 – Means, confidence interval widths and percent changes in means for selected summary statistics for the impact of the CAIS program on drainage

	Without CAIS		With CAIS		% Change
Variable	Mean	Std Dev	Mean	Std Dev	In Mean[a]
Wetlands Drained (ha)	22.76	19.76	23.91	20.33	5.07%
Cropped Basins Drained (ha)	4.36	5.06	4.60	5.15	5.33%
Percent of Wet Areas Drained on Owned Land	45.39%	25.61%	47.70%	25.99%	5.10%
Percent of Wet Areas Drained on Total Land Operated	34.38%	19.80%	36.13%	20.10%	5.09%
Perpetuity NPV Difference[b]	$8,616	$11,223	$9,389	$12,197	8.97%
Perpetuity NPV Difference per Hectare Drained[b]	$300	$354	$314	$373	4.87%
Percentage of Iterations where Perpetuity NPV was Positive	76.50%		76.80%		0.39%
PV of Cost of Drainage Conducted[c]	$468	$215	$475	$210	1.50%

Notes: [a] Percent changes in means are calculated for the case where the farm operator does not participate in the CAIS program. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value.

Increased mean returns for farms that participated in the CAIS program due to government portions of program payments probably caused the increase in area drained. This enabled farm operators participating in CAIS to undertake more drainage at higher PVs of cost per hectare drained. The percentage of iterations where the perpetuity NPV difference was positive also increased. However, standard deviations for the NPV summary statistics were greater for farms enrolled in CAIS. The standard deviations for the NPV outputs were likely higher because more expensive drainage projects involve a greater level of risk; returns to these projects are higher under favorable conditions and lower in unfavorable conditions.

6.1.9 Scenario 8 – Impact of Fixed Initial Land Base Allocation

Two representative farms, each comprised of an initial allocation of quarter sections that remained the same throughout the entire simulation, were examined in this scenario. In other words, the quarter sections were not randomly drawn for each iteration. This scenario was performed to examine the potential variability in results caused by the characteristics of the quarter sections. Two cases are considered: one where the nature of the wetlands is conducive to drainage (Fixed Farm 1) and another where it is not. In this scenario, confidence intervals, minimum levels and maximum levels are presented since a fixed land base was used and, under this assumption, these values do provide more insight. Detailed results for this scenario are provided in Appendix L in Tables L.19 and L.20.

Fixed Farm 1 initially possessed 420 hectares of cropland and 100 ha of wetlands and cropped basins on its eight quarters sections. The average yearly revenue for the farm, assuming it conducted no drainage over the 20-year period, would be approximately $129,000. This was somewhat less than that of the representative farm used in Scenario 1, which had average yearly revenues of $137,000. This difference was due to the larger initial endowment of wet area that Fixed Farm 1 had since wetland areas provide no revenue and cropped basins only produced crops in six out of ten years.

Table 6.10 indicates that Fixed Farm 1 drained, on average, 42 ha of land (39.90 hectares of wetlands and 2.15 hectares of cropped basins). This area represented 64% of the wet area on land the farm operator owned and 42% of wet area on the total area operated. The standard deviations, confidence levels and minimum and maximum values for these variables revealed that the level of drainage was still highly variable even though the initial land base did not change throughout the simulation. This provided an indication of how the variability in commodity prices and crop yields impacted drainage decisions. In iterations where yields and/or prices generated farm returns that were higher than average returns, more drainage would have been undertaken by the farm operator. The number of years it took to drain a quarter section was 3.04 years. Projects would take longer than three years to complete if the crop matured late because of poor weather during the growing season and/or if weather in the fall did not cooperate and few workdays were available to perform field operations.

Summary outputs for NPVs indicate that it was economically feasible for Fixed Farm 1 to purchase drainage equipment and drain wet areas (Table 6.10). Mean NPV values were approximately $635,000 when the farm operator drained land and $628,000 when the farm operator did not. The farm operator was, on average, able to realize a positive NPV of $7,105 through drainage, or $144/ha drained. In 70% of the iterations, a positive NPV was attained through conducting drainage. However, the 5% confidence interval and the minimum values for NPV differences in Table 6.10 indicated that significantly negative returns to drainage could potentially be experienced. This finding suggests that

Table 6.10 – Selected summary statistics for a representative farm that purchased a scraper to conduct drainage relative to performing no drainage that had a fixed initial land base with an endowment of wetlands greater than the average for the RM that were, on average, more conducive to drainage

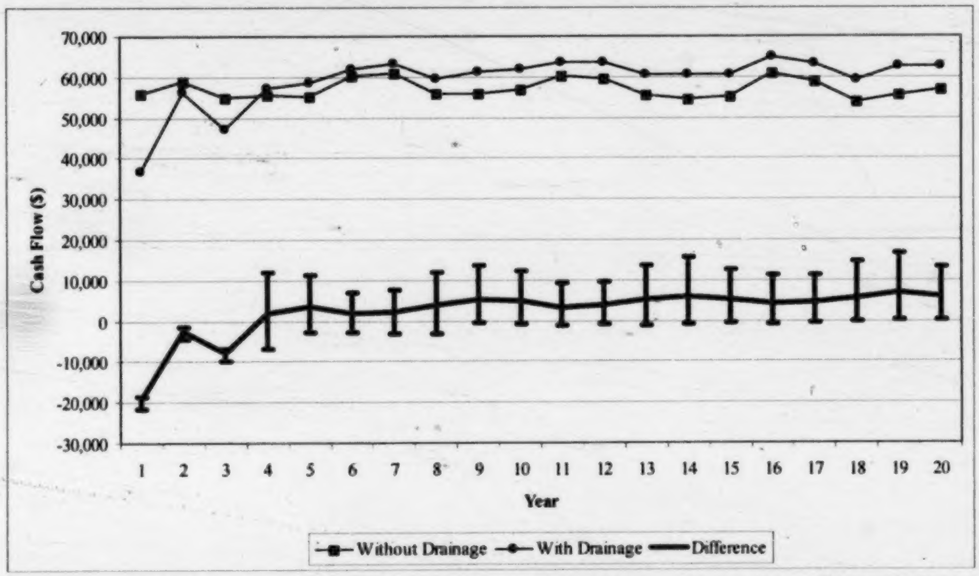
Variable	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Wetlands Drained (ha)	39.90	12.22	28.06	68.31	28.06	78.48
Cropped Basins Drained (ha)	2.15	0.92	0.79	3.77	0.79	4.65
Percent of Wet Area Drained on Owned Land	63.68%	13.49%	43.69%	89.74%	43.69%	89.74%
Percent of Wet Area Drained on Total Land Operated	42.01%	8.90%	28.83%	59.20%	28.83%	59.20%
Number Years to Drain a Quarter Section	3.04	0.10	3.00	3.25	3.00	3.80
Perpetuity NPV Without Drainage[a]	$628,005	$173,341	$361,845	$949,232	$169,095	$1,237,765
Perpetuity NPV With Drainage[a]	$635,110	$182,313	$357,854	$974,910	$154,261	$1,293,005
Perpetuity NPV Difference[a]	$7,105	$12,183	-$9,867	$28,535	-$33,176	$61,594
Perpetuity NPV Difference per Hectare Drained[a]	$144	$266	-$284	$581	-$761	$1,040
Percentage of Iterations where Perpetuity NPV was Positive	70.00%					
PV of Cost of Drainage Conducted[b]	$402	$101	$267	$594	$202	$749
Yearly Cash Flow Without Drainage	$57,087	$16,206	$32,000	$85,918	$12,265	$107,810
Yearly Cash Flow With Drainage	$59,318	$17,209	$33,058	$89,677	$11,947	$116,232

Notes: [a] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value.

the farm operator should consider the downside risk when deciding whether to invest in drainage equipment.

Figure 6.5 provides insight into mean cash flow and mean cash flow differences experienced by Fixed Farm 1 when its cultivated land base was expanded through drainage relative to not undertaking drainage. On average, mean cash flows increase from about $57,000/year to $59,000/year through drainage. Cash flows are similar to those exhibited in Scenario 1. For this farm, however, the confidence intervals for differences in cash flow became strictly positive by year 20. This finding provides further evidence that, for this particular farm, investing in drainage equipment would be economically feasible.

Figure 6.5 – Cash flows and differences in cash flows over 20 years for a representative farm that purchased a scraper to perform drainage relative to performing no drainage with a fixed land base consisting of quarter sections more conducive to drainage



Note: The vertical bars on cash flow difference represent the 90% confidence interval around the mean.

The PV of drainage costs was, on average, $402/ha and also indicated that drainage was a rational decision since this value was significantly lower than the average cost of purchasing land in the RM of Emerald ($640/ha). However, the farm operator should consider that it takes three years before benefits of drainage begin to accrue, whereas crops can be seeded in purchased land immediately.

The second farm analyzed, Fixed Farm 2, initially possessed 460 ha of cropland and 63 ha of wetlands and cropped basins on its eight quarters sections. The average yearly revenue for the farm, assuming it conducted no drainage over the 20-year period would be approximately $141,000. This was slightly greater than that of the representative farm used in Scenario 1, which had yearly average revenues of $137,000. This difference was due to the difference in the initial endowment of wet area on this farm; more cropland area resulted in higher revenues. A summary of results for this farm is provided in Table 6.11.

Table 6.11 indicates that only 22 hectares of land (20.96 ha of wetlands and 1.04 ha of cropped basins), on average, were drained by Fixed Farm 2, which is approximately half of what was drained by Fixed Farm 1. This area represented 51% of the wet area on land the farm operator owned and 35% of the wet area on the total area operated. The standard deviations, confidence levels and minimum and maximum values for these variables revealed that the level of drainage was quite variable, although not as variable as Fixed Farm 1. This provided an indication of how the variability in commodity prices and crop yields impacted drainage decisions. In iterations where yields and/or prices generated farm returns that were higher than average returns, more drainage would have been undertaken by the farm operator. On average it took 3.01 years to complete drainage on a quarter section. This was only slightly greater than the assumed value of three years since few drainage projects were undertaken by the farm operator.

Table 6.11 – Selected summary statistics for a representative farm that purchased a scraper to perform drainage relative to performing no drainage that had an initial fixed land base with an endowment of wetlands less than the average for the RM that were, on average, less conducive to drainage

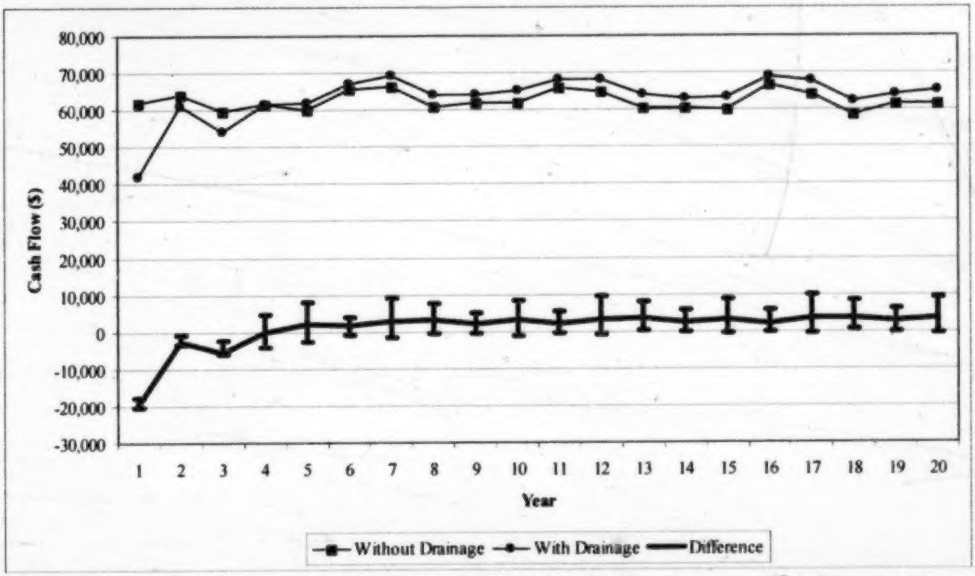
Variable	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Wetlands Drained (ha)	20.96	5.09	19.38	31.13	8.77	50.24
Cropped Basins Drained (ha)	1.04	1.38	0.56	4.23	0.26	7.90
Percent of Wet Area Drained on Owned Land	50.88%	11.15%	46.12%	71.76%	20.88%	90.29%
Percent of Wet Area Drained on Total Land Operated	34.92%	7.65%	31.65%	49.25%	14.33%	61.96%
Number Years to Drain a Quarter Section	3.01	0.06	3.00	3.00	3.00	3.80
Perpetuity NPV Without Drainage[a]	$686,669	$189,418	$396,157	$1,039,429	$186,124	$1,353,056
Perpetuity NPV With Drainage[a]	$680,981	$194,097	$382,989	$1,041,783	$165,628	$1,367,957
Perpetuity NPV Difference[a]	-$5,689	$6,776	-$16,170	$5,946	-$23,797	$17,105
Perpetuity NPV Difference per Hectare Drained[a]	-$284	$323	-$800	$246	-$1,937	$657
Percentage of Iterations where Perpetuity NPV was Positive	20.50%					
PV of Cost of Drainage Conducted[b]	$543	$68	$411	$639	$243	$860
Yearly Cash Flow Without Drainage	$62,400	$17,713	$35,270	$93,494	$13,433	$118,248
Yearly Cash Flow With Drainage	$63,275	$18,238	$35,135	$94,947	$12,706	$121,661

Notes: [a] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value.

Summary outputs indicate that it was not economically feasible for Fixed Farm 2 to purchase drainage equipment and drain wet areas. Mean NPV values were about $681,000 when the farm operator drained land and $687,000 when the farm operator did not. The performance of the farm was $5,689 lower when the farm operator conducted drainage. Each hectare drained reduced the performance of the farm by $284 relative to conducting no drainage at all. Positive returns to drainage were attained in only 20.50% of the iterations. Although, the 95% confidence level and maximum value indicated that positive returns to drainage were possible.

Figure 6.6 provides insight into mean cash flow and mean cash flow differences experienced by Fixed Farm 2 when its cultivated land base was expanded through drainage relative to not undertaking drainage. On average, mean cash flows increased from about $62,000/year to $63,000/year through drainage. Cash flows were similar to those exhibited by Fixed Farm 1. For this farm, however, the confidence intervals for differences in cash flow were much narrower. Less land was drained by this farm relative to Fixed Farm 1, which resulted in the narrow confidence interval. Fewer hectares drained exposed the farm operator to less risk when commodity prices and/or crop yields experienced after the projects were completed resulted in lower returns per hectare than the farm operator used in drainage decision calculations. Also, confidence intervals for cash flows in Figure 6.6 began to rise above zero by year 20 and the PV of costs of drainage conducted by Fixed Farm 2 was, on average, lower than the cost of purchasing land in the study area ($543/ha versus $640/ha). However, the overall results suggest that it would not be in the best interest of the farm operator to invest in drainage equipment.

Figure 6.6 – Cash flows and differences in cash flows over 20 years for a representative farm that purchased a scraper to conduct drainage relative to performing no drainage that had a fixed initial land base consisting of quarter section less conducive to drainage



Note: The vertical bars on cash flow difference represent the 90% confidence interval around the mean.

A comparison of the results for Fixed Farm 1 and Fixed Farm 2 suggested that the economic feasibility of drainage was highly dependent on the characteristics of the quarter sections that the farm operator owns. Some farms would be comprised of quarter sections that have significant hectares and numbers of wet areas that are economically feasible to drain while others would not.

6.1.10 Scenario 9 – Historical Analysis of Drainage[46]

The results for Scenario 1 indicated that, on average, it was not economically feasible for a farm comprised of eight quarter sections to purchase a scraper to conduct drainage projects under current economic conditions. However, in the RM of Emerald, nearly all quarter sections have drainage ditches on them and there are farm operators in the study area that currently own scrapers. Thus, at some point in time it must have been economically feasible for farm operators to purchase drainage equipment. This scenario examines this possibility. For this scenario, a representative farm of four quarter sections following a rotation of canola-wheat-summerfallow was used because, historically, farms were smaller and summerfallow was more common. Summaries of all output variables for this scenario are provided in Appendix L in Table L.21.

Table 6.12 reveals that during the simulation, the farm operator drained, on average, a total of 45.60 hectares of land (41.12 hectares of wetlands and 4.48 hectares of cropped basins). These figures represented nearly 90% of the wet area on land the farm operator owned and 68% of the wet area on the total land operated. Only about one-third of wet area on the total land operated would remain. Currently, however, approximately 59% of the estimated initial endowment of wetlands remains in the RM of Emerald. Since the model was not specifically designed as a historical simulation model, it was not surprising that the estimate of remaining wetlands determined through the simulation model and the estimation procedure in section 3.3 did not correspond.

On average, it took the farm operator 4.24 years to complete drainage on a quarter section. Projects would take longer than four years to complete if the crop matured late because of poor weather during the growing season and/or if weather in the fall did not cooperate and few workdays were available to perform field operations. Also, mean nuisance costs for this farm totaled approximately $1,200/year before any drainage was conducted, which represented just over 3% of total variable costs. Drainage would reduce these costs and provide the farm operator with more time to devote to field operations during the growing season.

Historically, it appeared that purchasing a scraper to conduct drainage was economically feasible (Table 6.12). The perpetuity calculations suggest that a representative farm comprised of four quarter sections would, on average, improve its financial well-being by $15,000 by investing in drainage equipment. Each hectare of drained land, on average, improved the performance of the farm by $258 relative to not draining land. These findings indicated that the returns to drainage were once sufficiently large to warrant investments in drainage equipment.

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[46] Estimated historical values for wetland area and counts were used as outlined in section 5.3.2. These values were greater than those used in all other scenarios.

Table 6.12 – Selected means of summary statistics for a representative farm that purchased a scraper to conduct drainage relative to performing no drainage under historical assumptions

Variable	Mean	Std Dev
Wetlands Drained (ha)	41.12	20.44
Cropped Basins Drained (ha)	4.48	4.41
Percent of Wet Area Drained on Owned Land	89.82%	17.56%
Percent of Wet Area Drained on Total Land Operated	67.58%	15.88%
Number Years to Drain a Quarter of Land	4.24	0.37
Initial Machinery Nuisance Cost Total for Farm[a]	$906	$138
Initial Input Waste Nuisance Cost Total for Farm[a]	$261	$40
Initial Nuisance Costs as a percentage of Total Variable Costs[a]	3.12%	0.37%
Perpetuity NPV Difference[b]	$15,078	$25,117
Perpetuity NPV Difference per Hectare Drained[b]	$258	$530

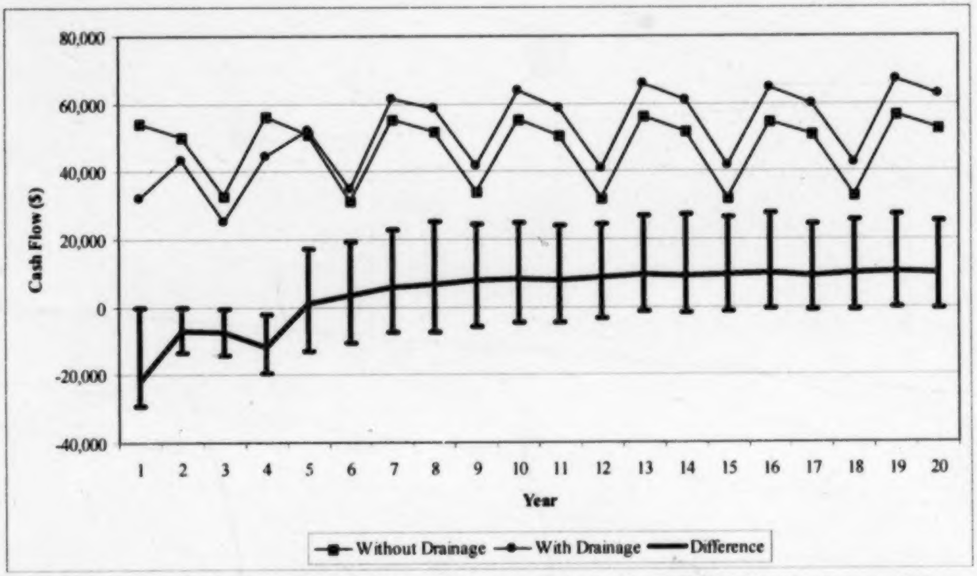
Notes: [a] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage.

Standard deviations of NPV variables in Table 6.12 were large relative to the averages and confidence intervals of non-discounted cash flows shown in Figure 6.7 were wider than in previous scenarios. Other cash flow graphs had confidence intervals less than $15,000 in width, whereas in Figure 6.7 the confidence interval was in excess of $20,000 for most years. The historical prices used in the simulation resulted in higher returns per hectare, which enabled the farm operator to undertake more drainage projects at higher costs per hectare. This resulted in a wider confidence interval because the more expensive drainage projects involve greater levels of risk. Returns to such projects are higher under favorable conditions and lower in unfavorable conditions.

The smaller farm size also impacted the standard deviations and confidence intervals since the quarter sections were changed for every iteration of 20-years. In one iteration, the farm may have been comprised of quarter sections that were among the most economically feasible to drain, whereas in another, it may have been comprised of quarter sections that were among the least economically feasible to drain. For larger farm sizes, this would be less common since the probability that all quarter sections chosen for a single iteration were among the most or least economically feasible to drain decreases. Therefore, even though drainage does appear to be economically feasible on average in this scenario, returns to drainage could be significantly negative if a particular farm was comprised of quarter sections where the costs to drain were sufficiently high and/or the benefits from drainage were low. The farm operator would then drain few hectares of land and the cultivated hectares gained would not provide sufficient benefits to justify purchasing a scraper.

Mean non-discounted cash flows over the 20-year simulation period shown in Figure 6.7 reveal that when the farm performed drainage cash flows were lower until year five when they became larger. By year 13, mean cash flow differences approached $10,000. The confidence interval for the difference in cash flows always included zero suggesting that the differences in cash flows were not statistically significant. However, over the course of the simulation the 5% confidence level became closer to zero. The peaks and valleys were caused by the small farm size and the 3-year crop rotation used that included summerfallow. The valleys coincide with years that two of the four quarter sections were being fallowed.

Figure 6.7 – Cash flows and differences in cash flows over 20 years for a representative farm that purchased a scraper to conduct drainage relative to performing no drainage under historical assumptions



Note: The vertical bars on cash flow difference represent the 90% confidence interval around the mean.

6.2 Sensitivity Analysis

Sensitivity analysis was performed to assess the impact of parameters for which limited information was available. Each analysis was performed utilizing one of the basic scenarios where the farm operator purchased a scraper, rented a scraper, or already possessed a scraper. This was done to determine if these parameters have a larger impact on the different scenarios and test whether the findings from the scenario analyses would change. However, conducting the sensitivity analysis in this manner did not permit direct comparisons across all sensitivity analyses.

6.2.1 Sensitivity Analysis 1 – Number of Years to Complete a Drainage Project

Through consultation with DUC, it was determined that three to four years would be an appropriate time frame to complete a drainage project on a quarter section. Crops could therefore be sown in these areas in either the fourth or fifth year after beginning construction of drainage ditches. All scenarios except for Scenario 9 presented in the previous section used the assumption that it would take three years to complete a drainage project on a quarter section. The sensitivity of results to this assumption is tested by now assuming that it would take four years to complete a drainage project. Results for this analysis were compared to Scenario 1, where the farm operator was initiating drainage and purchased a scraper prior to conducting drainage projects. Detailed results for this analysis are provided in Appendix L in Tables L.1 and L.22.

Increasing the number of years it took to complete the construction of drainage ditches did not have a major impact on the key outputs (Table 6.13). The total hectares drained over the course of the simulation decreased by 2.31 hectares (8%) when increasing the number of years it took to complete a drainage project. The associated percentages of land drained also decreased by about 8%.

Table 6.13 – Comparison of mean results for increasing the number of years to complete a drainage project from three to four for a representative farm that purchased a scraper to conduct drainage relative to performing no drainage

	Length of Time to Drain a Quarter Section Scenario		
Variable	3 years Mean	4 years Mean	% Change Mean[a]
Wetlands Drained (ha)	24.09	22.19	-7.90%
Cropped Basins Drained (ha)	4.65	4.24	-8.81%
Percent of Wet Area Drained on Owned Land	48.07%	44.18%	-8.10%
Percent of Wet Area Drained on Total Land Operated	36.42%	33.49%	-8.05%
Perpetuity NPV Difference[b]	-$5,404	-$6,460	-19.55%
Perpetuity NPV Difference per Hectare Drained[b]	-$384	-$442	-14.98%
Percentage of Iterations where Perpetuity NPV was Positive	22.00%	19.20%	-12.73%
PV of Cost of Drainage Conducted[c]	$482	$426	-11.68%

Notes: [a] Percent changes are calculated from the initial assumption for years to complete a drainage projects, 3 years. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value.

Increasing the number of years it took to complete a drainage project from three to four years made drainage appear less attractive (Table 6.13). Therefore, drainage was still not economically feasible. This is not surprising given that requiring an extra year to complete drainage on a quarter section means waiting an extra year before being able to generate cropping revenues from that area, which would reduce the NPV associated with drainage project. The mean perpetuity difference between the two cases analyzed exhibited the largest change among variables in Table 6.13 (-20%). The absolute difference was only about $1,000; therefore, the decision to invest in drainage equipment for simulations that have a positive mean NPV of less than $1,000 under the initial assumption of three years to complete a drainage project would be rejected using the assumption of four years to complete a drainage project. However, in cases where the NPV difference is less than $1,000, the economic feasibility of investing in drainage equipment to conduct drainage would be marginal. A farm operator contemplating drainage in this situation should consider factors other than solely the NPV difference before making a decision to invest in drainage.

6.2.2 Sensitivity Analysis 2 – Drainage Cost Assumptions

Two variables within the model pertain to drainage costs, the time to construct one meter of ditch and rehabilitation costs per hectare. In the scenario analyses, it was assumed that 0.20 hr were required to construct a meter of drainage ditch and rehabilitation costs were $200/ha. In this section, the sensitivity of the results to changes in these parameters is assessed. Two additional simulations were performed for this analysis. The first simulation used a value for the time to construct one meter of drainage ditch of 0.15 hr/m and rehabilitation costs of $150/ha, whereas the second simulation used a value for the time to construct one meter of drainage ditch of 0.25 hr/m and rehabilitation costs of $250/ha. Results of these simulations were then compared to the base results for Scenario 2 where the farm operator was initiating drainage and rented a scraper to conduct drainage projects. Detailed results for this analysis correspond to Tables L.3, L.23, and L.24 in Appendix L.

The simulation outputs were quite sensitive to drainage cost assumptions (Table 6.14) Using the low cost assumptions resulted in larger changes in summary variables than using high cost assumptions. Using lower costs increased the means of variables pertaining to area drained by more than 30%, whereas the higher cost assumptions resulted in decreases in the means of variables pertaining to area drained of about 20%. It was expected that the average number of years to drain a quarter section would be impacted by changing the time to construct one meter of ditch. However, it appears that for this farm size, the farm operator had enough time available to perform drainage regardless of how long it took to construct one meter of ditch.

The largest percent changes among output variables were for the values relating to the mean NPV difference between when the farm performed drainage and when it did not (Table 6.14). The mean NPV difference rose by over 45% using the low cost assumptions and decreased by over 25% using the high cost assumptions. When calculated on a per hectare basis, however, these values were less sensitive. This is important because estimates of incentive payments are affected in the same manner. Stable estimates for incentive payments provide a level of confidence in these values.

The conclusion regarding the economic feasibility of drainage did not change when using the high cost assumptions; all mean NPV variables remained positive. When using the high cost assumptions, however, positive NPVs only occurred in 54% of the iterations when the farm operator conducted drainage relative to not performing drainage. This suggests that performing drainage would involve a higher level of risk if drainage costs were actually higher than those assumed in the scenario analyses. Using low cost assumptions increased the mean PV of drainage costs to $458 since more drainage was conducted during the simulation period. However, this was still considerably lower than the cost of purchasing land in the RM of Emerald ($640/ha).

Table 6.14 – Means and percentage changes for selected summary statistics under different drainage cost assumptions for a representative farm that rented a scraper to conduct drainage relative to performing no drainage

		Drainage Cost Sensitivity Scenario			
	Scenario 2	Low Cost		High Cost	
Variable	Mean	Mean	% Change Mean[a]	Mean	% Change Mean[a]
Wetlands Drained (ha)	13.09	18.51	41.39%	10.04	-23.28%
Cropped Basins Drained (ha)	2.65	3.51	32.57%	2.25	-15.30%
Percent of Wet Area Drained on Owned Land	26.43%	36.72%	38.93%	20.88%	-21.01%
Percent of Wet Area Drained on Total Land Operated	20.05%	27.83%	38.86%	15.78%	-21.26%
Number Years to Drain a Quarter Section	3.01	3.02	0.25%	3.01	-0.07%
Perpetuity NPV Difference[b]	$5,300	$7,731	45.88%	$3,889	-26.62%
Perpetuity NPV Difference per Hectare Drained[b]	$280	$321	14.69%	$223	-20.38%
Percentage of Iterations where Perpetuity NPV was Positive	61.00%	69.60%	14.10%	54.00%	-11.48%
PV of Cost of Drainage Conducted[c]	$427	$458	7.27%	$415	-2.95%

Notes: [a] Percentage changes are calculated from the Scenario 2 values. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value.

6.2.3 Sensitivity Analysis 3 – Frequency of Crop Losses in Cropped Basins

In this analysis, the sensitivity to the frequency that yields were 0 tonnes/ha in cropped basins was examined since no information on these losses for the study area was available. In the scenario analyses, it was assumed that yields of 0 tonnes/ha would be experienced in 4 out of every 10 years. Two alternative cases were investigated here in order to test the sensitivity of the results to this assumption. The first had yields of 0 tonnes/ha in these areas in 2 out of every 10 years, whereas the second had yields of 0 tonnes/ha in 6 out of every 10 years. Results for this analysis were compared to Scenario 1 where the farm operator was initiating drainage and purchased a scraper prior to performing drainage projects. Detailed results for this analysis are provided in Appendix L in Tables L.1, L.25, and L.26.

Results for this sensitivity analysis revealed that most outputs were not sensitive to changes in assumptions regarding the frequency of crop losses in cropped basins (Table 6.15). Variables pertaining to area drained exhibited percent changes of less than 10%. Reducing the frequency where yields of 0 tonnes/ha were experienced reduced the area drained over the course of the simulation by 0.83 ha, whereas increasing it resulted in 0.81 ha more drainage. As expected, changing this assumption resulted in larger percentage changes in the mean area of cropped basins drained relative to the mean area of wetlands drained. The number of years it took to perform drainage on a quarter section changed only marginally since the total area drained changed only slightly.

Although increasing the frequency of crop losses in cropped basins to 6 out of 10 years made drainage appear more attractive, the conclusion that it was not economically feasible to drain still held (Table 6.15). As expected, decreasing the frequency in which yields of 0 tonnes/ha were experienced reduced the attractiveness of drainage. Changes in the means of the NPV differences between when the farm expanded its cultivated land base through drainage and when it did not exhibited the greatest sensitivity to changes this assumption. As in other sensitivity analyses, when these NPV differences were reported on a per hectare basis, the percentage changes were not as large and provide a level of confidence in the annual incentive payments calculated from these values. The percentage of iterations where positive NPV differences were experienced improved to 28% from 22% when the frequency of crop losses in cropped basins was increased, whereas it dropped to 18% when this variable was decreased The mean PVs of drainage costs changed only slightly since the area drained did not change significantly.

Table 6.15 – Means and percentage changes for selected summary statistics for different assumptions regarding the number of years out of ten where crop yields were 0 tonnes/ha in cropped basins for a representative farm that purchased a scraper to conduct drainage relative to performing no drainage

		Crop Loss Frequency Scenario			
	Scenario 1	2 years out of 10		6 years out of 10	
Variable	Mean	Mean	% Change Mean[a]	Mean	% Change Mean[a]
Wetlands Drained (ha)	24.09	23.63	-1.91%	24.59	2.07%
Cropped Basins Drained (ha)	4.65	4.28	-8.00%	4.96	6.68%
Percent of Wet Area Drained on Owned Land	48.07%	46.61%	-3.04%	49.57%	3.11%
Percent of Wet Area Drained on Total Land Operated	36.42%	35.34%	-2.95%	37.52%	3.04%
Number Years to Drain a Quarter Section	3.11	3.10	-0.29%	3.11	0.05%
Perpetuity NPV Difference[b]	-$5,404	-$7,101	-31.41%	-$3,629	32.85%
Perpetuity NPV Difference per Hectare Drained[b]	-$384	-$455	-18.52%	-$324	15.68%
Percentage of Iterations where Perpetuity NPV was Positive	22.00%	18.30%	-16.82%	28.20%	28.18%
PV of Cost of Drainage Conducted[c]	$482	$477	-1.02%	$495	2.59%

Note: [a] Percentage changes are calculated from the Scenario 1 values. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value.

6.2.4 Sensitivity Analysis 4 – Drained Area Yields Relative to Upland Yields

Crop yield in drained areas relative to their upland (i.e. non-wetland) counterparts was another variable for which little information was available. In the scenario analyses, it was assumed there was no differential between yields on drained areas and yields on upland areas. This assumption was made to essentially provide a conservative estimate of any cropping benefits from drainage decisions. However, information that was collected pertaining to drained area yields suggests that yields in these areas could be greater than upland areas (Lyseng, 2002; Wanchuk, 1986).

The sensitivity of results to changes in this variable was examined in this section. Two cases are presented, one in which yields in drained areas were 5% greater than upland yields and another where yields were 10% greater than upland yields. Results of this analysis were compared to Scenario 3 where the farm operator already owned drainage equipment and was conducting additional drainage. Detailed results for this analysis are provided in Appendix L in Tables L.4, L.27, and L.28.

Including yield advantages in drained areas relative to the rest of the field did not produce large changes in most summary outputs (Table 6.16). One of the most important findings of this analysis was that percent changes for variables pertaining to area drained were less than 5% even when a yield advantage of 10% was assumed. At a 5% yield advantage, area drained and percentages of wet area drained increased by less than 2% and by only about 3.5% when a 10% yield advantage was assumed.

Table 6.16 – Means and percentage changes for selected summary statistics for different assumptions regarding the yield in drained wetland areas relative to the rest of the field for a representative farm that already owned drainage equipment and conducted additional drainage relative to performing no additional drainage

		Wet Area Yield Scenario			
	Scenario 3	5% Yield Advantage		10% Yield Advantage	
Variable	Mean	Mean	% Change Mean[a]	Mean	% Change Mean[a]
Wetlands Drained (ha)	23.91	24.34	1.77%	24.75	3.51%
Cropped Basins Drained (ha)	4.60	4.67	1.58%	4.75	3.24%
Percent of Wet Area Drained on Owned Land	47.70%	48.53%	1.74%	49.38%	3.51%
Percent of Wet Area Drained on Total Land Operated	36.13%	36.76%	1.74%	37.39%	3.48%
Number Years to Drain a Quarter Section	3.19	3.21	0.37%	3.22	0.75%
Perpetuity NPV Difference[b]	$9,389	$11,411	21.53%	$13,463	43.38%
Perpetuity NPV Difference per Hectare Drained[b]	$314	$377	19.95%	$437	38.97%
Percentage of Iterations where Perpetuity NPV was Positive	76.80%	80.00%	4.17%	83.70%	8.98%
PV of Cost of Drainage Conducted[c]	$475	$482	1.56%	$489	3.07%

Note: [a] Percentage changes are calculated from the Scenario 3 values. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value.

Relative increases in yields in wet areas did not alter returns to drainage enough to significantly increase the mean area a farm operator would drain. Changes in the means of the NPV difference and the NPV difference reported on a per hectare basis between when the farm performed drainage and when it did not were the variables that exhibited the greatest sensitivity to changes in assumptions for this variable (Table 6.16). This had implications for estimates of incentive payments offered to farm operators. Incentive payments would rise by approximately $6/ha/year for every five percentage point increase in drained area yields relative to the rest of the field[47]. Assuming that there was a yield advantage in drained areas also reduced the risk involved in conducting drainage as the percent of iterations where positive NPV differences were experienced increased from 77% to 80% and 84% for 5% and 10% yield advantages, respectively. The mean PVs of drainage costs changed only slightly since few additional hectares were drained when yield advantages in drained areas were assumed.

6.2.5 Sensitivity Analysis 5 – Sensitivity to Different Crop Rotations

All scenario analyses performed and discussed thus far assumed a 5-year rotation of canola-barley-flax-wheat-summerfallow. This analysis examined the sensitivity of the results to this assumption. This was done by modeling two alternative crop rotations: a canola-wheat-summerfallow rotation and a continuous cropping rotation of canola-barley-flax-wheat. All crop rotations used crops predominantly grown in the study area and were based on expert opinion. In both cases the farm was assumed to already own drainage equipment and to be conducting additional drainage. Results of this analysis were compared to Scenario 3. Detailed results for this analysis are provided in Appendix L in Tables L.4, L.29, and L.30.

The results reported in Table 6.17 reveal that output results were quite sensitive to changing the crop rotation used from the original assumption to the continuous cropping rotation. Absolute values of the percent changes were about twice as large for the canola-barley-flax-wheat rotation when compared to the percent changes using the canola-wheat-summerfallow rotation relative to the canola-barley-flax-wheat-summerfallow rotation.

Variables pertaining to the area of wetlands and cropped basins drained in Table 6.17 exhibited a high degree of sensitivity to the crop rotation. Nearly 30% more land (7.93 ha) was drained, on average, when using the continuous cropping rotation relative to the crop rotation used in Scenario 3. However, only 13% less drainage (3.73 ha), on average, was conducted when the canola-wheat-summerfallow rotation was employed. Drained area represented 61% of wet area on land the farm operator owned and 46% of the wet area on the total land operated when the continuous cropping rotation was employed, whereas drained area represented 41% of wet area on land the farm operator owned and 31% of the wet area on the total land operated when utilizing the canola-wheat-summerfallow rotation.

The average time to complete drainage on a quarter section increased to 3.57 years from 3.19 years when utilizing the continuous cropping rotation and dropped to 3.10 years when the canola-wheat-summerfallow rotation was used. The changes were caused by the differences in hectares drained. Larger, more expensive projects were generally undertaken when more hectares were drained, which made it more difficult for a farm operator to complete a project in the assumed three year time period.

Nuisance costs were also affected by the crop rotation used. Mean total nuisance costs experienced by the farm rose by $265 when using the continuous cropping rotation and decreased by $207 when the canola-wheat-summerfallow rotation was employed. Changes in nuisance costs would alter the incentives to drain. For example, fewer machinery operations were required on quarter sections in summerfallow; therefore lower nuisance costs were experienced and incentives to drain would be lower.

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[47] Each five percentage point increase in drained area yield relative to the rest of the field increased the value of a drained hectare of land by approximately $60. Through the use of simple annuity calculation, the annual value of this increase is $6.

Table 6.17 – Means and percentage changes for selected summary statistics for different assumptions regarding crop rotations for a representative farm that owned a scraper and conducted additional drainage relative to performing no additional drainage

		Crop Rotation Scenario			
	Scenario 3	C-B-F-W[a]		C-W-S[b]	
Variable	Mean	Mean	% Change Mean[c]	Mean	% Change Mean[c]
Wetlands Drained (ha)	23.91	30.59	27.90%	20.79	-13.07%
Cropped Basins Drained (ha)	4.60	5.85	27.29%	3.99	-13.17%
Percent of Wet Area Drained on Owned Land	47.70%	61.29%	28.48%	41.38%	-13.25%
Percent of Wet Area Drained on Total Land Operated	36.13%	46.39%	28.39%	31.37%	-13.18%
Number Years to Drain a Quarter Section	3.19	3.57	11.70%	3.10	-2.88%
Initial Machinery Nuisance Cost Total for Farm[d]	$1,590	$1,762	10.82%	$1,420	-10.69%
Initial Input Waste Nuisance Cost Total for Farm[d]	$536	$629	17.33%	$499	-6.96%
Initial Nuisance Costs as a percentage of Total Variable Costs	2.51%	2.45%	-2.53%	2.47%	-1.82%
Perpetuity NPV Difference[e]	$9,389	$15,507	65.15%	$6,870	-26.83%
Perpetuity NPV Difference per Hectare Drained[e]	$314	$402	27.97%	$261	-16.90%
Percentage of Iterations where Perpetuity NPV was Positive	76.80%	84.30%	9.77%	72.60%	-5.47%
PV of Cost of Drainage Conducted[f]	$475	$579	21.94%	$423	-10.97%

Notes: [a] C-B-F-W stands for the canola-barley-flax-wheat rotation. [b] C-W-S represents the canola-wheat-summerfallow rotation. [c] Percentage changes are calculated from the Scenario 3 values. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted. [e] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [f] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value.

The changes in the means of the NPV difference when the farm expanded its land base through drainage and when it did not showed the greatest sensitivity to changes in assumptions for this variable (Table 6.17). This variable increased by 65% when using the continuous cropping rotation and decreased by 27% when the canola-wheat-summerfallow was utilized. However, when these NPV differences were reported on a per hectare basis, the percentage changes were not as large and provided a level of confidence in annual incentive payments calculated from these values. This high degree of sensitivity was, for the most part, caused by large differences in returns per hectare for the different crop rotations; summerfallow provides no revenue and therefore significantly decreased returns per hectare over the crop rotation period. Given the assumptions used in this analysis, the expected value of average returns per hectare over each rotation were approximately $140, $175 and $125 for the canola-barley-flax-wheat-summerfallow, canola-barley-flax-wheat, and canola-wheat-summerfallow rotations, respectively. Higher returns per hectare under the continuous cropping rotation provided an incentive for the farm operator to undertake a greater number of drainage projects over the simulation period. Changes in nuisance costs, as discussed in the previous paragraph, would have also provided additional incentives to drain land in this case.

The percentage of iterations where positive NPV differences were experienced through drainage did not change significantly when utilizing different crop rotations. This variable increased by 10% when using the continuous cropping rotation and decreased by 5% when the canola-wheat-summerfallow rotation was utilized. It was also interesting to note that the mean PV of drainage costs when using the continuous cropping rotation was $579/ha, which approached the cost of purchasing land in the study area ($640/ha). Drainage, however, still appeared to be an attractive alternative to purchasing additional land.

6.2.6 Sensitivity Analysis 6 – Sensitivity to Changes in Commodity Prices

The initial commodity prices used in all scenarios described thus far, except the historical analysis, were 10-year averages over the period 1993-2002. To examine sensitivity to changes in prices, two different price levels were utilized: commodity prices from the year 2002 and 5-year average prices over the period 1998-2002. Five-year average prices were slightly lower than 10-year average prices and 2002 prices were slightly higher for all commodities except canola. These alternative price levels were the starting prices for the simulation and also the mean values of the price distributions for each year of the distribution. Results of this analysis were compared to Scenario 1 where it was assumed that farm operators had not conducted any previous drainage and that they purchased the necessary equipment prior to doing so. Detailed results for this analysis are presented in Tables L.1, L.31, and L.32 in Appendix L.

Outputs appear somewhat sensitive to changes in commodity prices (Table 6.18). The results were more sensitive to changes in commodity prices than changes in crop yields but less sensitive than changes in the crop rotation. Changes related to the area drained over the course of the simulation increased by 12%-15% when utilizing the higher price levels and decreased by 13% when the lower price levels were used. Total area drained increased by 3.84 ha under the high price assumption and decreased by 3.77 ha under the low price assumption.

The most sensitive output variable in Table 6.18 was the difference between the mean NPVs between the two alternative actions of the farm, expanding its cultivated land base through drainage and maintaining its existing land base. Although utilizing the higher price levels from the year 2002 improved the results for conducting drainage, the conclusion regarding economic feasibility did not change from Scenario 1. It was still not economically feasible for a farm comprised of eight quarters sections to invest in drainage equipment. The percentage of iterations where positive NPV differences were experienced increased to 31% under the high price assumption and decreased to 17% under the low price assumption. The mean PV of the cost of drainage performed by the farm operator remained below the cost of land in the study area ($640/ha) in both cases indicating that drainage appeared to be an attractive alternative to purchasing land. However, drainage does not appear to be in the farm operator's best interest in any of the cases analyzed here.

Table 6.18 – Means and percentage changes for selected summary statistics for different assumptions regarding crop rotations for a representative farm that purchased a scraper to conduct drainage relative to performing no drainage

		Alternative Price Scenario			
	Scenario 1	2002 Price		5-year Price	
Variable	Mean	Mean	% Change Mean[a]	Mean	% Change Mean[a]
Wetlands Drained (ha)	24.09	27.38	13.64%	20.93	-13.13%
Cropped Basins Drained (ha)	4.65	5.20	11.89%	4.04	-13.14%
Percent of Wet Area Drained on Owned Land	48.07%	54.61%	13.60%	41.73%	-13.19%
Percent of Wet Area Drained on Total Land Operated	36.42%	41.34%	13.52%	31.62%	-13.17%
Perpetuity NPV Difference[b]	-$5,404	-$3,120	42.26%	-$6,933	-28.29%
Perpetuity NPV Difference per Hectare Drained[b]	-$384	-$288	25.12%	-$478	-24.47%
Percentage of Iterations where Perpetuity NPV was Positive	22.00%	30.70%	39.55%	17.20%	-21.82%
PV of Cost of Drainage Conducted[c]	$482	$540	12.05%	$419	-13.15%

Note: [a] Percentage changes are calculated from the Scenario 1 values. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value.

6.2.7 Sensitivity Analysis 7 – Sensitivity to Changes in the Discount Rate

The final sensitivity analysis evaluated the sensitivity of results to changes in the discount rate. The appropriate discount rate for a Western Canadian grain farm was determined to be 10%[48]. For the sensitivity analysis, discount rates of 8% and 12% were used and compared to the results for the assumed 10% discount rate. This analysis assumed that the farm operator had not conducted any previous drainage and that they purchased the necessary equipment prior to doing so. Results of this analysis were compared to Scenario 1. Detailed results for this analysis are provided in Appendix L in Tables L.1, L.33, and L.34.

Using 8% and 12% discount rates had similar but opposite effects for variables related to area drained relative to the 10% discount rate (Table 6.19). Hectares drained were not considerably sensitive to changes in the discount rate. The values increased by about 17% using the lower discount rate and decreased by approximately 15% using the higher discount rate.

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[48] Choice of discount rate was discussed in section 5.2.4.6.

On the other hand, different discount rate assumptions caused large changes in NPV outputs. Results in Table 6.19 were more sensitive to decreases in the discount rate than increases in the discount rate. A higher discount rate reduced the attractiveness of performing drainage, whereas the lower discount rate substantially improved the attractiveness of drainage.

Table 6.19 – Means and percentage changes for selected summary statistics for different discount rate assumptions for a representative farm that purchased a scraper to conduct drainage relative to performing no drainage

		Alternative Discount Rate Scenario			
	Scenario 1	8%		12%	
Variable	Mean	Mean	% Change Mean[a]	Mean	% Change Mean[a]
Wetlands Drained (ha)	24.09	28.38	17.79%	20.54	-14.75%
Cropped Basins Drained (ha)	4.65	5.42	16.57%	3.94	-15.16%
Percent of Wet Area Drained on Owned Land	48.07%	56.70%	17.95%	40.91%	-14.91%
Percent of Wet Area Drained on Total Land Operated	36.42%	42.94%	17.92%	31.00%	-14.87%
Perpetuity NPV Difference[b]	-$5,404	$1,233	122.83%	-$8,199	-51.72%
Perpetuity NPV Difference per Hectare Drained[b]	-$384	-$166	56.93%	-$536	-39.59%
Percentage of Iterations where Perpetuity NPV was Positive	22.00%	42.40%	92.73%	11.00%	-50.00%
PV of Cost of Drainage Conducted[c]	$482	$607	25.96%	$398	-17.54%

Note: [a] Percentage changes are calculated from the Scenario 1 values. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value.

One particularly interesting result is that at the lower discount rate of 8%, the mean difference in NPVs between when the farm performed drainage and when it did not appeared to indicate that it would be economically feasible for a farm operator to purchase a scraper to conduct drainage. However, positive NPV differences only occur in 42% of the iterations and the mean NPV difference calculated on a per hectare basis was negative suggesting that one would be better off not investing in drainage equipment. This apparent inconsistency was caused by the logarithmic price distribution assumed in the model and the fact that the amount of drainage conducted in each iteration was different. Since the capital cost of the scraper was explicitly considered in this analysis, extremely large negative values occur in iterations when few hectares are drained. These large negative values resulted in a negative value for the mean NPV difference per hectare drained. Regarding the price distribution, the distribution for the logarithm of each price was normally distributed. When these prices were converted back to dollars per tonne value to be used in cash flow calculation, the distribution would be skewed right. This implied that the extremes for high prices were further from the mean than the extremes for low prices and the mean of such a distribution was greater than the mode. Because of this, the mean of the distribution for the difference in NPVs between when the farm conducted drainage and when it did not could be positive when a positive NPV difference only occurred in 42% of the iterations. Utilizing the 8% discount rate also resulted in a mean PV of drainage costs ($607/ha) that approached the average cost of purchasing land in the study area ($640/ha). Taking all the information into account suggested that it would still not be economically feasible to undertake drainage in this case.

6.3 Chapter Summary

Results for Scenarios 1 through 3 suggested that it was not economically feasible for a large farm in the RM of Emerald (within the top quartile of all farms in the RM by revenue) to purchase drainage equipment and conduct drainage. However, drainage was feasible if this farm operator was able to rent a scraper or already possessed the necessary equipment. On average, 28.51 ha of land was drained by a farm operator that already owned drainage equipment, whereas only slightly over half of that total (15.74 ha) was drained, on average, by a farm operator that rented drainage equipment. Nearly 50% of wet area on land the farm operator owned was drained in the scenario where the farm operator owned a scraper. Nuisance costs for the representative farm in all three scenarios initially total approximately $2,000 or 2.5% of variable costs.

Scenario 4 checked whether a farm operator should drain only wetlands as opposed to both wetlands and cropped basins. Findings indicated that draining both wetlands and cropped basins, provided marginally better returns to drainage than draining only wetlands.

Scenario 5 analyzed how the scale of operations could impact the economic feasibility of drainage. Results revealed that the farm size where drainage becomes economically feasible for farm operators purchasing scrapers falls between 16 and 20 quarter sections. However, it is expected that positive returns to drainage would be experienced if operators of smaller farms were able to obtain used scrapers at costs below the capital cost used in the analysis or found other farm operators interesting in sharing the cost of a scraper. All farms that owned scrapers were able to improve their performance through drainage. Larger farms experienced slightly greater returns per hectare.

Incentives to maintain wetland resources were also discussed in Scenario 5. The payments estimated would be made on the hectares of wetlands conserved. Incentives for farm operators that would need to purchase equipment prior to conducting drainage were not necessary unless a farm was comprised of about 20 quarter sections. In this case, if an organization were interested in protecting specific wetland areas, $5/ha/year would be sufficient, whereas $3/ha/year would be needed to conserve all wetlands on land owned by the farm operator. These estimates of incentive payments were comparable to those currently offered through a pilot tax credit program in Saskatchewan. These estimates, however, should be used with caution since farm operators could obtain drainage equipment at lower costs than used in this analysis.

Incentive payments for farms that already possessed drainage equipment ranged from $26/ha/year to $38/ha/year if an organization were to protect specific wetland areas on a farm and $12/ha/year to $19/ha/year if an organization was interested in conserving all wetlands on land a farm operator owns. Estimates of incentive payments for farm operators that owned drainage equipment calculated in this study were at least four times greater than incentive payments currently offered through a pilot tax credit program in Saskatchewan.

Per hectare payments to farm operators that rent scrapers, although not explicitly estimated, would be slightly less than those made to farm operators that currently own scrapers. However, payments to conserve all wetlands on land a farm operator owns would be approximately half the amounts estimated for those farm operators that possessed drainage equipment since it was noted that the farm operator drained about half as much land when a rented scraper was used.

Nuisance costs were the focus of Scenario 6 and were found to be an important factor in the drainage decision. Approximately 35% of the mean difference in NPVs estimated for when the farm performed drainage relative to not conducting drainage was attributable to reduced nuisance costs, whereas the other 65% was from additional crop revenues. It was also shown that nuisance cost assumptions could potentially have a greater impact on larger farms that possess larger equipment. In cases where an estimate of nuisance costs was included, about 10%-15% more land was drained, on average, than when nuisance costs were assumed to be zero. A comparison of nuisance costs between the estimates in this study and the limited information available was also included. The comparison suggested that nuisance cost estimates used in this model were consistent with results from previous studies.

Farm programs were analyzed in Scenario 7. Increased returns per hectare for participants in the CAIS program provided farm operators with incentives to drain more land. At the farm level, the increase in the area of drained land was not large, representing about 1.5 ha. However, if these results were extrapolated over a large geographical region, additional wetland drainage would be considerably more significant.

Scenario 8 considered the impact of using the same initial land base in all 1,000 iterations of the simulation. The objective of the scenario was to show how the characteristics of the quarter sections influenced the economic feasibility of drainage. It was revealed that a farm operating eight quarter sections of land could experience positive returns to drainage given a land base that was conducive to drainage. Another farm of the same size could experience exceedingly negative returns to drainage given a land base that was not conducive to drainage.

A historical analysis was performed in the final scenario. This scenario was used to determine whether it was economically feasible in the past for farm operators to purchase scrapers to conduct drainage. Model assumptions were changed to best represent historical conditions. The results indicated that a farm could have realized positive returns to drainage under historical assumptions.

Seven sensitivity analyses were performed in total. Simulation results proved most sensitive to cropping rotation, discount rates and drainage costs. Results appeared to be less sensitive to factors such as length of time to complete drainage on a quarter section, commodity prices, the frequency with which crop yields were 0 tonnes/ha in cropped basins, and drained area yields relative to upland areas. The mean NPV difference between when the farm conducted drainage and when it did not exhibited the greatest sensitivity. However, this did not change the conclusions reached for cases that were compared directly to the various scenario analysis results. Net present value differences calculated on a per hectare basis generally showed considerably less volatility than the other NPV difference variable, which provided some confidence in the incentive payments calculated from these values. However, the sensitivity analyses were performed using different assumptions for how scraper costs were incorporated into the analysis, which did not facilitate direct comparisons of results across all analyses.

Chapter 7: Conclusions and Limitations

This study addressed the problem of wetland drainage in Western Canada. Specifically, the economics of surface drainage conducted by the farm operator through the use of their own equipment was analyzed for representative farms in the RM of Emerald in east-central Saskatchewan. The objectives of the study were to: (1) to determine the economic feasibility of wetland drainage for a representative farm in the study area, (2) to estimate the value of drained lands to farm operators, and (3) to assess the risk further wetland loss in the region. The focus was not to promote wetland drainage, but to determine whether or not wetland drainage was a rational decision for farm operators. The value of drained lands to farm operators determined through the analysis facilitated the estimation of potential incentive payments that could be used for wetland preservation. However, direct payments to farm operators are only one of a host of policy instruments that could be used to conserve wetlands.

The problem was analyzed using NPV analysis and Monte Carlo simulation. The model developed was a stochastic dynamic model that simulated the performance of a representative farm over a 20-year period. The model simulated the performance of a farm when it conducted drainage and when it did not. The results of the analysis provided insight into drainage in the study area. The conclusions presented in this chapter are based on the results provided by the analysis conducted. Limitations of the model were also revealed in the analysis and suggestions for further research into these areas are offered.

7.1 Conclusions

The findings of this study are intended to be useful to individuals and organizations interested in preserving wetland resources. The results, as presented in the thesis, are only applicable to the study area (i.e. the RM of Emerald in Saskatchewan) and are dependent on several assumptions pertaining to wetland drainage and farming practices in the area. However, the modeling approach used in this study could be applied to other areas of Saskatchewan and Western Canada given relevant data for the stochastic variables, input costs, land, machinery costs, farm programs, and drainage costs.

7.1.1 The Economic Feasibility of Drainage

The performance of a farm when it expanded its cultivated land base through drainage relative to when it did not was compared using NPVs as a proxy for the impact of drainage on wealth. This analysis revealed that, on average, drainage was economically feasible in the RM of Emerald. The economic feasibility of drainage was analyzed for farms that had not previously conducted any drainage and for farms that were assumed to have already conducted drainage in previous years. It was assumed that those farms that had not previously conducted drainage were required to either purchase or rent drainage equipment prior to performing drainage on their land. Farms that had previously drained areas were assumed to be maintaining existing drainage ditches and contemplating further drainage. Findings indicated that for any farm that currently possessed drainage equipment, further reclamation of land would be economically feasible. On the other hand, results suggested that, on average, it would be difficult for farm operators considering purchasing drainage equipment to realize positive returns to drainage unless their farm was sufficiently large.

Results for farms that needed to acquire drainage equipment prior to initiating drainage were generally negative. For farms that had a representative distribution of wet areas in their quarter sections, the simulation results suggested that a farm operator would need to operate nearly 20 quarter sections before purchasing a scraper to conduct drainage was economically feasible. The large cash outflow associated with the purchase of a scraper in the early years of the simulation period resulted in poorer performance when drainage was conducted relative to when it was not for farms comprised of less than 20 quarter sections.

On the other hand, some quarter sections were much more conducive to drainage than others, so the results would depend heavily on the characteristics of the quarter sections the farm owned. Therefore, a farm operator that had less than 20 quarters sections comprised of quarter sections that were conducive to drainage could experience positive returns to drainage. Also, if a farm operator were able to obtain a used scraper at a lower cost than the capital cost of a scraper used in this analysis, drainage could become economically feasible. A farm operator could also share the cost of a scraper with other farm operators interested in drainage, which could lead to positive returns. Renting drainage equipment was also an option available to farm operators where it did not appear economically feasible to purchase a scraper. Renting drainage equipment to conduct drainage always improved the performance of the farm relative to conducting no drainage. However, variable costs associated with renting equipment were higher, which reduced the number of hectares that were economically feasible to drain. Utilizing assumptions from years past indicated that returns to drainage were once much higher, which justifies why farm operators currently own drainage equipment.

The cost of draining land as a means to expand one's cultivated land base was also compared to purchasing land in the area. Using recent land sales in the area, the average cost of land in the RM of Emerald was determined to be $640/ha. Present values of drainage costs incurred over the simulation period were approximately $500/ha. Given that the cost of draining lands through drainage was less than the cost of purchasing land, it was rational for farm operators to consider using drainage to expand their cultivated land base. However, farm operators need to analyze their own situation to before conducting drainage to assess whether it would actually improve their returns.

Additional machinery and input costs incurred from maneuvering around wetland obstacles in quarter sections, nuisance costs, had a significant impact on drainage decisions. Leitch (1983) noted that when only additional crop benefits were considered in NPV calculations, farm operators would conduct drainage projects that resulted in apparent negative NPVs, which is not rational unless other potential benefits such as nuisance costs were being ignored in the calculations. This study used previous research to develop estimates of nuisance costs experienced by farm operators. Nuisance cost assumptions used in this analysis indicated that for farms experiencing positive NPVs through drainage, approximately 35% of the improvement in farm performance was attributed to reduced nuisance costs. The remaining 65% of benefits resulted from additional crop revenues.

Sensitivity analysis revealed that crop rotations, drainage costs, and discount rates had significant impacts on the economic feasibility of drainage. Farm operators could generate significantly higher returns to drainage utilizing continuous cropping rotations. Crops other than those used in the present study could also potentially alter the returns generated from drainage. With regards to drainage costs, if mean drainage costs were lower/higher than those used in the present analysis, returns to drainage could increase/decrease considerably. Farm operators that have different levels of experience draining lands could experience mean drainage costs that are lower/higher than those used in the current study and realize improved/reduced returns from drainage. Lower discount rates substantially improved the attractiveness of drainage, whereas higher discount rates reduced the performance of the farm when it conducted drainage. On the other hand, it did not appear that yields in drained areas, the frequency with which crop yields were 0 tonnes/ha in cropped basins, commodity prices, nor the length of time to complete drainage on a quarter section would dramatically affect drainage returns unless they were significantly different from those used in the present analysis.

7.1.2 Wetland Loss

The positive returns to drainage found in many of the drainage scenarios examined in this study suggest that further wetland loss in the RM of Emerald can be expected. For farms that purchased scrapers and farms that conducted additional drainage, simulation results indicated that 45%-55% of wet area on land owned by farm operators or 35%-40% of wet area on the total land operated was potentially at risk of drainage. Farm operators performing drainage utilizing rented equipment would drain about half this amount. In the RM of Emerald, about 41% of the initial wetland area has already disappeared. To provide a worst case scenario for the RM of Emerald, if all farm operators either acquired a scraper or owned a scraper, as much as 65% of the initial endowment of wetlands could disappear if drainage continued.

Farm programs, specifically the new Canadian Agricultural Income Stabilization program, improve expected returns and reduce risk associated with farming. Findings indicated that participation in the CAIS program created additional incentives to drain land because of the improved returns and decreased risk associated with crop production. Resulting increases in area drained were not significant at the farm level; however, when extrapolated to larger geographical areas, the amount of additional land drained would become considerable.

7.1.3 Implications for Wetland Conservation

To arrest further wetland loss in the RM of Emerald, farm operators may need to be provided with direct payments to encourage maintenance of wetlands. Danielson and Leitch (1986) suggest that farm operators would accept payments that compensate them for the benefits of drainage forgone. However, direct incentive payments are only one of a host of policy instruments that could be used to conserve wetlands.

In this study, annual incentive payments made on wetland hectares were estimated. These incentive payments could be offered to farm operators to maintain their wetland resources. The incentive payments were estimated using the average NPV difference between when a farm conducted drainage and when it did not. Differences in NPVs were calculated on a per hectare drained basis and converted to average annual payments using a simple annuity calculation. These payments could be used to protect wetlands that are at risk of being drained. However, average payments were also calculated on a per hectare of wetlands owned basis since individuals and organizations interested in wetland conservation do not necessarily know which wetlands are at risk of drainage. Payments calculated on a per hectare of wetlands owned could be used to protect all wetlands that are on land owned by a farm operator.

One finding from this analysis was that average incentive payments increased as the size of the farm increased. This was because farms that operated more land were assumed to possess larger machinery complements and it was assumed that nuisance costs would increase with the width of machinery implements. This increased the benefits resulting from drainage because greater cost reductions were experienced through drainage.

Average incentive payments for farms that possessed drainage equipment and conducted additional drainage were estimated to be $26/ha/year for small farms (4 quarter sections in size) and $38/ha/year for large farms (20 quarter sections in size) for each hectare of land drained. On a per hectare of wetlands owned basis these payments were $12/ha/year for small farms and $19/ha/year for large farms. Incentive payments for farm operators that purchased scrapers did not appear necessary, since it was estimated that drainage, on average, was not economically feasible unless the farm was sufficiently large (approximately 20 quarter sections). However, it would be possible for those farm operators to realize positive returns to drainage if they were able to buy a used scraper, share the cost of a scraper with other farm operators that were interested in drainage, or rent a scraper. The possibility of renting a scraper was analyzed in this study and the results indicated that incentive payments per hectare drained would be slightly less than those estimated for farm operators that owned drainage equipment and conducted additional drainage. However, incentive payments per hectare owned would be about half of what was estimated for farms that owned drainage equipment and conducted additional drainage. Higher variable costs associated with scraper rentals caused lower returns per hectare to drainage and lower estimates of area drained by farm operators renting drainage equipment. This suggests that all farms with wetland resources may need to be compensated, although those without the necessary drainage equipment could potentially be compensated with lower payments.

Payments to all farms that possess wetland resources in the RM of Emerald would be expensive at rates suggested in this study. Compensating all farm operators in the province of Saskatchewan would be considerably more costly. Therefore, targeting certain wet areas or farm operators for payments would be a more feasible strategy for organizations funding such payments. Findings from Desjardins (1983) indicated that wet areas along the side or in the corner of a quarter section were less of a nuisance than those that a farm operator must drive completely around. This finding suggests that incentive payments for these wet areas could be as much as one-third less than those previously discussed. More area at lower cost could be protected by targeting payments in this manner.

It should be noted that the analysis in the present study was conducted on a cash flow basis and therefore only cash flow items were used in the model. Fixed costs were not included since they did not differ between the two alternative actions of the farm operator, expanding their cultivated land base through drainage or maintaining their existing cultivated land base. Opportunity costs for labour or equity were not factored into the analysis either. As discussed in Chapter 6, if these opportunity costs were incorporated into the analysis, the estimated incentive payments made to farm operators to forgo drainage would undoubtedly be affected. A farm operator could spend the time devoted to drainage activities earning off-farm income or as leisure time. However, as noted earlier, by removing wetland obstacles drainage also potentially increases time flexibility for farm operators during critical points in the crop production process. Therefore, the direction of change in the value of direct incentive payments from incorporating opportunity costs of labour cannot be predicted in general.

7.2 Model Limitations and Further Research

Several assumptions were made based on limited data. The results of this study could change if new research were conducted to improve estimates used in this research. Several areas are identified in this section where future research could be conducted to increase understanding of drainage in the study area and develop better policy instruments for wetland conservation. Specific future research recommendations would be in the areas of determining drainage costs for surface projects conducted by the farm operator with their own equipment, estimating nuisance costs, determining wetlands at risk of drainage, and valuation of the social costs of drainage for the study area.

7.2.1 Drainage Assumptions

Estimating costs associated with drainage was among the most difficult components of the present research. Estimates of costs pertaining to constructing ditches and those relating to nuisance costs were based on relatively little information. Drainage projects conducted in the study area are surface drainage projects performed by the farm operator with their own equipment. Due to the nature of this type of drainage, costs are highly variable and this is likely one reason why few studies of this type have been undertaken. Drainage costs for this research were developed to fit within a range estimated by the Saskatchewan Wetland Conservation Corporation (1993). The costs used in this research do exhibit a high degree of variability, which appears to represent reality. However, whether or not mean costs estimated by the model actually represent those experienced by farm operators is impossible to confirm. Results of the study are sensitive to the drainage cost assumptions, especially if drainage costs are actually lower than those used in the analysis. Conducting a survey of farm operators that drain lands in the area would provide another basis for estimating the costs of these projects.

The regression analysis used in estimating ditch length required to drain a quarter section was based on counts of wet areas in quarter sections and the total area comprised by these wet areas. No attempt was made to incorporate the spatial arrangement of the wet areas in the quarter sections into the regression equation. Adding variables that considered, for example, the proximity of the wet areas to each other would yield more appropriate estimates of the length of drainage ditch required to drain each quarter section. Given that the data collected are in geographic information system (GIS) format, adding these sorts of variables to the regression equation would be possible for future research on this topic.

Future research in the area of nuisance costs is also warranted. Under the assumptions used in this study, it was revealed that reductions in nuisance costs from drainage activities represent a significant portion of the overall benefits from drainage. Nuisance costs also appear to be highly variable between quarter sections and between farm operators. The characteristics and configuration of wetlands in quarters sections and driving patterns of farm operators cause this variability (Accutrak Systems Ltd., 1991). The method used to estimate nuisance costs in this study does not appear to replicate this variability. Nuisance costs were based on estimates of how numbers of wetlands and machinery widths impact time spent in a quarter section and input waste. It was not possible to account for other attributes specific to each quarter section that could impact nuisance costs. These could include the complexity of the shape of each wetland and their distribution within the quarter section. Further research is currently underway to yield better estimates of these costs by attempting to mimic driving patterns of farm operators in quarter sections. However, as previously mentioned, driving patterns of farm operators have also been shown to be quite variable and can significantly influence nuisance costs attributed to maneuvering around wetland obstacles (Accutrak Systems Ltd., 1991).

A couple of other aspects of nuisance costs exist were not estimated within this study either. Cropped basins do represent nuisances in the spring when they are too wet to cultivate. Farm operators must also maneuver around these obstacles in addition to wetlands in these instances and they often return to seed these areas once they dry out. These areas may be seeded to different crops than the rest of the field and may mature at later dates, therefore having implications for subsequent field operations. Costs associated with delayed field operations were also not estimated within this model. An example of such costs is when additional time spent seeding because of wetland obstacles delays spraying operations. Late applications of pesticides can result in poor weed control and lower yields at harvest. A study by Aldabagh and Beer (1975) estimated these costs for a corn/soybean rotation and values used in calculation of these costs were provided in ASAE Standards (2000). However, no corresponding data exist for calculating these costs for Canadian agricultural production. Further research in this area would improve understandings of farm operators' motivations to drain.

In the simulation, it was assumed that the farm operator drained all wet areas in the entire quarter section or conducted no drainage at all in that particular quarter section. In reality, it would be possible for a farm operator to drain individual wetlands in each quarter section. However, considerably more programming effort would have been required to incorporate this into the model and it was deemed that adding this additional complexity to the model would not provide a significant improvement in the results.

Regulations related to drainage and wetland consolidation were also not considered in the model. Farm operators are expected to obtain authority prior to draining water off their land (Government of Saskatchewan, 2002). Lower returns to drainage would be expected if obtaining approval results in delays or prohibits drainage projects. On the other hand, if the farm oparator is not permitted to remove the water from their property, wetland consolidation would be a feasible alternative to removing all wet areas from the quarter section. Wetland consolidation could also result in significant gains in arable land and considerably lower nuisance costs if the farm operator were able to consolidate all water into the corner or along the side of a field. A farm operator may also prefer this method of drainage if they have other uses for the water. Consolidation was not considered as an option for the current study.

All wet areas on the quarter sections used in the model were assumed to be candidates for the type of drainage considered in this research. Due to quarter section and wetland characteristics, it is likely that not all wet areas could be drained using these methods. However, drainage costs per hectare for many quarter sections were quite high and drainage would only be conducted on these quarter sections during periods of favorable conditions (combinations of high prices and yield over several years). Nonetheless, the results from this study may be higher than if one were able to determine which areas were conducive to the type of drainage considered in this model. DUC is currently working on a model to estimate wetlands that are at risk of drainage. Results of their analysis could be easily incorporated into the type of model used in the present study.

7.2.2 Farm Assumptions

Farm operators in the model followed a strict crop rotation. In reality, farm operators make cropping decisions each year based on commodity prices and rotational requirements and do not adhere to a crop rotation as strictly as they do in this model. The model was also not able to utilize the complete range of crops grown in the area. Popular crops such as oats and field peas were not used in any of the rotations. On a related note, sensitivity analysis indicated that the results were most sensitive to changes in the crop rotation, especially when using a continuous cropping rotation. There is more incentive for those following a continuous cropping rotation to drain land and they receive higher benefits per hectare from doing so. More and more farms are shifting to continuous cropping practices.

7.2.3 Valuation of Social Costs of Drainage

The present study focused on the private benefits and costs associated with wetland drainage. However, wetlands provide numerous public good benefits that society highly values such as provision of wildlife habitat, amenity values, improvements in water quality, and hydrologic functions (Lupi Jr. et al., 1991). Numerous wetland valuation studies have been conducted; although the majority of them have been conducted in the United States. Due to the heterogeneity among wetlands, there exists a wide range of wetland values (Stavins, 1989). Therefore, including public benefits in the present analysis would require a wetland valuation study within the region analyzed. Benefits potentially provided by wetlands in the study area would be provision of waterfowl habitat and flood control.

There were also potentially additional costs associated with wetland drainage that were not incorporated into the present analysis. For example, downstream landowners could incur damages from increased run-off from drainage projects. Significant increases in drained lands could put pressure on municipal works as well and result in additional costs at the RM level. These costs could be reduced by adding features that control the rate at which water leaves the property.

Data were available for duck hunting benefits in Saskatchewan. These were estimated to be, on average, $45/ha and would be a lower bound for the value of wetland resources in the study area (Heimlich et al., 1998). However, no other data were available on social costs of wetland drainage. Including any social costs in the analysis would reduce the economic feasibility of drainage. Research studies that have analyzed the public feasibility of drainage often found that drainage was not in society's best interests (Cecile et al., 1985; van Vuuren and Roy, 1993; Elliot and Mulamoottil, 1992; Myhre, 1992).

The analysis in the current study implicitly assumes that farm operators are only concerned with direct costs and benefits associated with drainage decisions. In fact, these same farm operators may also consider public (i.e., environmental) benefits associated with maintenance of wetland areas (e.g., amenity values) when making these decisions. This would have a direct impact on the value of any direct payments or incentives required to encourage the retention of wetland areas on farming operations.

References

Accutrak Systems Ltd. 1991. A Study to Determine the Cost of Farming Around an Obstacle. Regina, Saskatchewan.

Agriculture and Agri-Food Canada (AAFC). 2004. Canadian Agricultural Income Stabilization (CAIS) Program Handbook. Ottawa, Ontario.

Aldabagh, A. S. Y and C. E. Beer. 1975. Economics of increased mobility from tile drainage. *Transactions of the ASAE* 18(1), 116-121.

American Society of Agricultural Engineers. 2000. *ASAE Standards 2000*. 47th ed. 350-357. American Society of Agricultural Engineers, St. Joseph, Michigan, United States.

Anthony, W. E. 1975. Basic Economics of Farm Drainage. Minnesota Agricultural Economist. Department of Applied Economics, University of Minnesota, St. Paul, Minnesota.

Arrow, K. J. and A. C. Fisher. 1974. Environmental Preservation, Uncertainty, and Irreversibility. *Quarterly Journal of Economics* 88(2), 312-19.

Baier, W. 1973.Estimation of Field Workdays in Canada from the Versatile Soil Moisture Budget. *Canadian Agricultural Engineering* 15(2), 84-87.

Bardecki, M. J. 1989. The Economics of Wetland Drainage. *Water Quality Bulletin* 14(2), 76-80, 103-104.

Bardecki, M. J. 1987. The Impact of Agriculture on Wetlands Conservation. Wetlands/Peatlands Symposium. August 23-27, Edmonton, Alberta.

Bardecki, M. J. 1984. Wetland conservation policies in southern Ontario: A Delphi approach. Atkinson College, York University, Downsview, Ontario.

Batt, B. D. J., M.G. Anderson, C.D. Anderson, and F.D. Caswell. 1989. The use of prairie potholes by North American ducks. In: *Northern Prairie Wetlands*. Edited by van der Valk, A.G. Iowa State University Press, Ames, Iowa.

Bauer, L. 1997. An Economic Analysis of the Costs and Returns Associated with the Use of Crown Grazing Dispositions in Alberta 1976-1996. The Alberta Cattle Commission.

Bedard, T. 2004. Combining Progress Reports. Saskatchewan Agriculture, Food and Rural Revitalization, Regina, Saskatchewan.

Belcher, K. W., M. M. Boehm, and M. E. Fulton. 2004. Agroecosystem sustainability: a system simulation model approach. *Agricultural Systems* 79(2), 225-241.

Biggs, B. 2004. Census of Agriculture Data 1996 and 2001. Agriculture Statistics Division - Farm Income and Prices, Statistics Canada, Ottawa, Ontario.

Boychuk, L. 2005a. Land Sales Data - RM of Emerald. Ducks Unlimited Canada. Regina, Saskatchewan.

Boychuk, L. 2005b. Quarter Section Data - RM of Emerald. Ducks Unlimited Canada, Regina, Saskatchewan.

Boychuk L. 2004. Weather Station Data - Kelliher and Wynyard. Regina, Saskatchewan, Ducks Unlimited Canada.

Boyle, K.J. Contingent Valuation in Practice. 2003. In: *A Primer on Nonmarket Valuation*. Edited by Champ, P.A., K.J. Boyle, and T.C. Brown. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Brace, R. K. and G. W. Pepper. 1984. Impact of Agricultural Drainage on Wildlife. Proceedings of the Third Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management - Agricultural Land Drainage.

Brouwer, R., S. Crooks, and R. K. Turner. 2003. Environmental indicators and sustainable wetland management. In: *Managing Wetlands*. Edited by Turner, R. K., J. C. J. M. van den Bergh, and R. Brouwer. Edward Elgar, Northampton, Massachusetts.

Brouwer, R., I. H. Langford, I. J. Bateman, and R. K. Turner. 1999. A meta-analysis of wetland contingent valuation studies. *Regional Environmental Change* 1(1), 47-57.

Bullock, P. R. 2004. Personal communication with Dr. Paul Bullock, Professor, University of Manitoba, Winnipeg, Manitoba, August 31, 2004.

Campbell, D. A., C. A. Cole, and R. P. Brooks. 2002. A comparison of created and natural wetlands in Pennsylvania, USA. *Wetlands Ecology and Management* 10, 41-49.

Canada Land Inventory. 1999. Overview of Classification Methodology for Determining Land Capability for Agriculture. Accessed August 9, 2004. http://sis.agr.gc.ca/cansis/nsdb/cli/classdesc.html

Cecile, C. P., M. J. Bardecki, and E. A Snell. 1985. The Eastern Ontario subsidiary agreement drainage program: impacts on the land resource. An initial evaluation. Lands Directorate, Environment Canada.

Chipanshi, A. C., E. A. Ripley, and R. G. Lawford. 1999. Large-scale simulation of wheat yields in a semi-arid environment using a crop-growth model. *Agricultural Systems* 59(1), 57-66.

Cooper, J. C. 1995. The Application of Nonmarket Valuation Techniques to Agricultural Issues. Natural Resources and Environment Division, Economic Research Service, Washington, D.C.,

Copeland, T. and V. Antikarov. 2003.*Real Options: a practitioner's guide*. New York, New York: TEXERE.

Copeland, T.E., J.F..Weston, and K. Shastri. 2005. Financial Theory and Corporate Policy. In: *Investment Decisions: The Certainty Case*. Pearson Addison Wesley, Boston, Massachusetts.

Corbally, M. and P. Dang. 2002. Underlying Markets and Derivatives. In: *Weather Risk Management: Markets, products and applications*. Palgrave., New York, New York.

Daniel, W.W. and J.C. Terrell. 1992. *Business Statistics for Management and Economics*. 6th ed. Houghton Mifflin Company, Toronto, Ontario.

Danielson, L. E. 1989. Changes in Wetlands Due to Agriculture. Luzer, E. J. and Henning, S. A. Alternative Perspectives on Wetland Evaluation and Use: Proceedings of a Regional Workshop. Publication No. 27, 18-24. Southern Natural Resource Economics Committee.

Danielson, L. E. and J. A. Leitch. 1986. Private vs. Public Economics of Prairie Wetland Allocation. *Journal of Environmental Economics and Management* 13(1), 81-92.

Debrah, S. and H. H. Hall. 1989. Data Aggregation and Farm Risk Analysis. Agricultural Systems 31, 239-245.

Desjardins, R. 1983. The Impact of Obstacles on Farm Operations. Resource Economics Branch, Alberta Agriculture.

Dixit, A.K. and R.S. Pindyck. 1994. *Investment Under Uncertainty*. Princeton University Press, Princeton, New Jersey.

Douglas, A. J. 1989. Annotated Bibliography of Economic Literature on Wetlands. United States Fish and Wildlife Service. Washington, D.C.,

Douglas, A. J. and R. L. Johnson. 1994. Drainage Investment and Wetlands Loss: an Analysis of the National Resources Inventory Data. *Journal of Environmental Management* 40, 341-355.

Ducks Unlimited Canada. 2004. Saskatchewan Tax Credit Program, Fall 2004 Bulletin. Regina, Saskatchewan.

Ducks Unlimited Canada. 2005. Physiological Crop Maturity Dates. Accessed March 10, 2005. http://www.wintercereals.ca/tools/weathermanager/hguides/sk/kelliher.html

Dugan, P.J. 1990.*Wetland Conservation: A Review of Current Issues and Required Action*. International Union of Conservation of Nature and Natural Resources, Gland, Switzerland.

Duku-Kaakyire, A. 2003. Evaluation of the Real Options Approach to Agribusiness Valuation: A Pork Investment Case Study. M. S. Thesis. Department of Rural Economy, University of Alberta, Edmonton, Alberta.

Dunan, C. M., F. D. Moore III, and P. Westra. 1994. A plant process-economic model for wild oats management decisions in irrigated barley. *Agricultural Systems* 45(4), 355-368.

Edwards, C. 2005. Personal communication with Cynthia Edwards, Agriculture and Policy Analyst, Ducks Unlimited Canada, Regina, Saskatchewan, April 29, 2005.

Eidman, V. 1997. Minnesota Farmland Drainage: Profitability and Concerns. *Minnesota Agricultural Economist.* Department of Applied Economics, University of Minnesota, St. Paul, Minnesota,

Elliot, L. and G. Mulamoottil, 1992. Agricultural and Marsh Land Uses on Walpole Island: Profit Comparisons. *Canadian Water Resources Journal* 17(2), 111-119.

Elliot, R. L., W. D. Lembke, and D. R. Hunt. 1977. A Simulation Model for Predicting Available Days for Soil Tillage. *Transactions of the ASAE* 20(1), 4-8.

Evans, J.R. and D.L. Olson. 2002. *Introduction to Simulation and Risk Analysis*. 2nd ed. Prentice Hall, Upper Saddle River, New Jersey.

Found, W. C., A. R. Hill, and E. S. Spence. 1976. Economic and environmental impacts of agricultural drainage in Ontario. *Journal of Soil and Water Conservation* 31(1), 20-24.

French, H.F. 1859. *Farm drainage: The principles, processes and effects of draining land with stones, wood, plows and open ditches and especially with tiles*. A.O. Moore, New York.

Fulton, J. R., R. P. King, and P. L. Fackler. 1988. Combining Farm and County Data to Construct Farm Level Yield Distributions. Staff Paper Series. Department of Agricultural and Applied Economics, University of Minnesota, St. Paul, Minnesota.

Gittinger, G.P. 1982. *Economic analysis of agricultural projects.* The John Hopkins Press, Baltimore, Maryland.

Goldsmith, A. and E.H. Clark II. 1990. Nonregulatory Programs Promoting Wetlands Protection. In: *Issues in Wetlands Protection: Background Papers Prepared for the National Wetlands Policy Forum*. Edited by Bingham, G., E. H. Clark II, and L. V. L. M. Haygood. The Conservation Foundation, Washington, D.C.

Goldstein, J.H. 1971. *Competition for Wetlands in the Midwest: An Economic Analysis*. Resources for the Future, Washington, D.C.

Government of Saskatchewan. 1978. The Conservation and Development Act. Chapter C-27 of The Revised Statutes of Saskatchewan. Regina, Saskatchewan.

Government of Saskatchewan. 1981. The Drainage Control Regulations. Chapter D-33.1, Reg 1. Regina, Saskatchewan.

Government of Saskatchewan. 2002. The Saskatchewan Watershed Authority Act. Chapter S-35.02 of the Statutes of Saskatchewan. Regina, Saskatchewan.

Gray, R. S., J. S. Taylor, and W. J. Brown. 1996. Economic Factors Contributing to the Adoption of Reduced Tillage Technologies in Central Saskatchewan. *Canadian Journal of Plant Science* 76(4), 661-668.

Griffiths, W.E., R.C. Hill, and G.G. Judge. 1993. *Learning and Practicing Econometrics*. John Wiley & Sons, Inc., Hoboken, New Jersey.

Hammack, J. and G.M. Brown. 1974. *Waterfowl and Wetlands: toward bioeconomic analysis*. Resources for the Future, Baltimore, Maryland.

Heimlich, R. E. and L. L. Langner. 1986. Swampbusting: Wetland Conversion and Farm Programs. Economic Research Service. Washington, D.C.

Heimlich, R. E., K. D. Wiebe, R. Claassen, D. Gadsby, and R. M. House. 1998. Wetlands and Agriculture: Private Interests and Public Benefits. Economic Research Service, Washington, D.C.

Hollands, G.G. 1990. Regional Analysis of the Creation and Restoration of Kettle and Pothole Wetlands. In: *Wetland Creation and Restoration: The Status of the Science*. Edited by Kusler, J.A. and M.E. Kentula. Island Press, Washington, D.C.

Hotz, J. C. 2004. An Evaluation of Value at Risk in the Alberta Pork Production Industry. M. S. Thesis. Department of Rural Economy, University of Alberta, Edmonton, Alberta.

Huel, D. 2000. Managing Saskatchewan's Wetlands: A Landowner's Guide. Saskatchewan Wetland Conservation Corporation, Regina, Saskatchewan.

Hull, J.C. 1997. *Options, Futures, and Other Derivatives*. Third Edition ed. Prentice Hall, Upper Saddle River, NJ.

Hulston, L. 2005. Crop Insurance Calculator. Saskatchewan Crop Insurance Corporation. Regina, Saskatchewan.

Hulston, L. 2004. RM of Emerald Crop Insurance Yields. Saskatchewan Crop Insurance Corporation, Regina, Saskatchewan.

Hursin, T. J. 1991. Wetland Retention on the Prairies through Private Landowner Stewardship. School of Community and Regional Planning, University of British Columbia, Vancouver, British Columbia,

Irwin, R. W. 1979. Field Survey of Drainage Benefits in Ontario. School of Engineering, Univeristy of Guelph, Guelph, Ontario.

Jeffrey, S. R. and F. S. Novak. 1999. Evaluating Alternative Safety Net Programs in Alberta: A Firm-level Simulation Analysis. Department of Rural Economy, Edmonton, Alberta.

Johnston, C. A. 1994. Cumulative impacts to wetlands. *Wetlands* 14, 47-55.

Kanwar, R. S., H. P. Johnson, D. Schult, T. E. Fenton, and R. D. Hickman. 1983. Drainage Needs and Returns in North-Central Iowa. *Transactions of the ASAE* 26(2), 457-464.

Ketchabaw, E. H. 1991. Relationships among agricultural tenancy, lease arrangements, land management and rent payments in Ontario. University of Guelph, Department of Agricultural Economics and Business, Guelph, Ontario.

Kramer, R. A. and L. A. Shabman. 1993. The Effects of Agricultural and Tax Policy Reform on the Economic Return to Wetland Drainage in the Mississippi Delta Region. *Land Economics* 69(3), 249-263.

Kusler, J.A. 1990. Views on Scientific Issues Relating to the Restoration and Creation of Wetlands. In: *Issues in Wetland Protection: Background Papers Prepared for the National Wetlands Policy Forum*. Edited by Bingham, G., E. H. Clark II, L. V. Haygood, and M. Leslie. The Conservation Foundation. Washington, D.C.

Kusler, J.A. and M.E. Kentula. 1990. *Wetland Creation and Restoration: The Status of the Science*. Island Press, Washington, D.C.

Law, A.M. and W.D. Kelton. 2000. *Simulation Modeling and Analysis*. 3rd ed. McGraw Hill, Boston, Massachusetts.

Leitch, J. A. 1983. Economics of Prairie Wetland Drainage. *Transactions of the ASAE* 26(2), 1465-1470.

Leitch, J.A. 1989. Politicoeconomic overview of prairie potholes. In: *Northern Prairie Wetlands*. Edited by van der Valk, A. G. Iowa State University Press, Ames, Iowa.

Leitch, J. A. 1984. Prairie Potholes and the Prairie Farmer. Proceedings of the Third Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management - Agricultural Land Drainage.

Leitch, J. A. and D. Kerestes. 1981. Agricultural Land Drainage Costs and Returns in

Minnesota. Department of Agricultural and Applied Economics, University of Minnesota, St. Paul, Minnesota.

Leitch, J. A. and D. F. Scott. 1977. Economic Impact of Flooding on Agricultural Production in Northeast Central Dakota. Department of Agricultural Economics, North Dakota State University, Fargo, North Dakota,

Leon's Manufacturing Company, Inc. 2005. Personal communication with Leon's Manufacturing Company, Inc. April 14, 2005.

Lupi Jr., F., T. Graham-Tomasi, and S. J. Taff. 1991.A Hedonic Approach to Urban Wetland Valuation. Department of Agricultural and Applied Economics, University of Minnesota, St. Paul, Minnesota.

Lynch-Stewart, P., C. D. A. Rubec, K. W. Cox, and J. H. Patterson. 1993. A Coming of Age: Policy for Wetland Conservation in Canada. North American Wetlands Conservation Council (Canada), Ottawa, Ontario.

Lyseng, Ron. 2002. Convert nuisance sloughs into productive acres. *Farming* 5(1), 18-21. The Western Producer, Saskatoon, Saskatchewan.

Manitoba Agriculture. 1985. Designing Surface Drainage Systems. Manitoba Agriculture. Soil Facts.

Marra, M. C. and B. W. Schurle. 1994. Kansas Wheat Yield Risk Measures and Aggregation: A Meta-Analysis Approach. *Journal of Agricultural and Resource Economics* 19(1), 69-77.

McColloch, P. R. and D. J. Wissman. 1988. Analysis of the Impact of Federal Programs on Wetlands in the Prairie Pothole Region. The Impact of Federal Programs on Wetlands. Volume 1: The Lower Mississippi Alluvial Plain and the Prairie Pothole Region. United States Department of the Interior, Washington, D.C.

McFarlane, M. 2004. Saskatchewan Conservation and Development Association Inc. *Watershed Network News* 2, 8.

Miller, J. D. 2002. Economics of Riparian Grazing Management. M. S. Thesis. Department of Rural Economy, University of Alberta, Edmonton, Alberta.

Mitsch, W.J. and J.G. Gosselink. 1993. *Wetlands*. New York, New York: van Nostrand Reinhold.

Mitsch, W. J. and R. F. Wilson. 1996. Improving the Success of Wetland Creation and Restoration with Know-How, Time and Self-Design. *Ecological Applications* 6(1), 77-83.

Morris, J. and T. M. Hess. 1986. Farmer uptake of agricultural land drainage benefits. *Environment and Planning A* 18, 1649-1664.

Myers, S.C. 1976. Using simulation for risk analysis. In: *Modern Developments in Financial Development*. Edited by Myers, S.C. Praeger, Westport, Conneticut.

Myhre, M. A. 1992. Economic Analysis of Drainage in Alberta. M. S. Thesis. Department of Rural Economy, University of Alberta, Edmonton, Alberta.

Nelson, R. W. 1986. Wetland Management Strategies Balancing Agriculture with Conservation: A National Survey of Expert Opinion. *The Environmental Professional* 8, 54-69.

Newcombe, D. 2004. Drainage Statistics. Saskatchewan Watershed Authority, Regina, Saskatchewan.

Nordblom, T. L., R. E. Jones, and R. W. Medd, 2003. Economics of factor adjusted herbicide doses: a simulation analysis of best efficacy targeting strategies (BETS). *Agricultural Systems* 76(3), 863-882.

Norwood, B., M. C. Roberts, and J. L. Lusk. 2004. Ranking Crop Yield Functions Using Out-of-Sample Likelihood Functions. *American Journal of Agricultural Economics* 86(4), 1032-1043.

Novak, J. 2005. Personal communication with Joe Novak, Provincial Specialist – Economic Analysis, Saskatchewan Agriculture, Food and Rural Revitalization, Regina, Saskatchewan, Ongoing from July, 2004 through April, 2005.

Novak, J. 2004. Crop Planning Guide 2003, Saskatchewan Agriculture, Food and Rural Revitalization, Regina, Saskatchewan.

Olewiler, N. 2004. The Value of Natural Capital in Settled Areas of Canada. Ducks Unlimited Canada and The Nature Conservancy of Canada.

Pallisade Corporation. 2002. *Guide to Using @Risk, Version 4.5*. Palisade Corporation, Newfield, New York.

Palmquist, R. B. and L. E. Danielson. 1989. A Hedonic Study of the Effects of Erosion Control and Drainage on Farmland Values. *American Journal of Agricultural Economics* 71(1), 57-62.

Parsons, G.R. 2003. The Travel Cost Model . In: *A Primer on Nonmarket Valuation*. Edited by Champ, P. A., K. J. Boyle, and T. C. Brown. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Pearson, G. G. and S. N. Kulshreshtha. 2002. An Economic Appraisal of Conservation and Development Area Authority Projects in Saskatchewan. Department of Agricultural Economics, University of Saskatchewan, Saskatoon, Saskatchewan.

Perillat, B. J., W. J. Brown, and R. D. H. Cohen. 2004. A risk efficiency analysis of backgrounding and finishing steers on pasture in Saskatchewan, Canada.

Agricultural Systems 80(3), 213-233.

Porter, R. M. and G. C. van Kooten. 1993. Wetlands Preservation on the Canadian Prairies: The Problem of the Public Duck. *Canadian Journal of Agricultural Economics* 41, 401-410.

Radke, B. 2004. Personal communication with Brian Radke, Research Economist, Alberta Agriculture, Edmonton, Alberta, October 6, 2004.

Rigaux, L. R. and R. H. Singh. 1977. Benefit-Cost Evaluation of Improved Levels of Agricultural Drainage in Manitoba. Department of Agricultural Economics and Farm Management, Winnipeg, Manitoba,

Ross, S.A., R.W. Westerfield, J.F. Jaffe, and G.S. Roberts. 2003. *Corporate Finance*. 3rd Canadian ed. McGraw-Hill Ryerson, Toronto, Ontario.

Rotz, C. A. 2004. Personal communication with C. Alan Rotz, Agricultural Engineer, United States Department of Agriculture, University Park, Pennsylvania, November 10, 2004.

Rotz, C. A., H. A. Muhtar, and J. R. Black. 1983. A Multiple Crop Machinery Selection Algorithm. *Transactions of the ASAE* 26(2), 1644-1649.

Rousseau, A. 1983. A Study of Costs and Benefits of On-Farm Surface Drainage in North-Central Alberta. Resource Economics Branch, Alberta Agriculture.

Rudstrom, M., M. Popp, P. Manning, and E. Gbur. 2002. Data Aggregation Issues for Crop Yield Risk Analysis. *Canadian Journal of Agricultural Economics* 50, 185-200.

Rutledge, P. L. and F. V. McHardy. 1968. The Influence of Weather on Field Tractability in Alberta. Canadian Agricultural Engineering 10(2), 70-73.

Saskatchewan Agriculture, Food and Rural Revitalization (SAFRR). 2004a. Agricultural Statistics 2003. Saskatchewan Agriculture, Food and Rural Revitalization, Regina, Saskatchewan.

Saskatchewan Agriculture, Food and Rural Revitalization (SAFRR). 2004b. Crop Districts Map. Accessed August 10, 2004. http://www.agr.gov.sk.ca/docs/reports/crop_report/Crdist.asp?firstPick=Crops&secondpick=Soil%20Fertility_Fertilizers&thirdpick=Null

Saskatchewan Agriculture, Food and Rural Revitalization (SAFRR). 2004c. Crop Yields by Rural Municipality. Accessed August 12, 2004. http://www.agr.gov.sk.ca/apps/rm_yields/default.asp?firstpick=Crop%20Yields%20by%20RM

Saskatchewan Agriculture, Food and Rural Revitalization (SAFRR). 2004d. Farm

Machinery Custom and Rental Rate Guide. Saskatchewan Agriculture, Food and Rural Revitalization, Regina, Saskatchewan.

Saskatchewan Crop Insurance. 2004. Saskatchewan Soil Zones Map. Accessed August 10, 2004. http://www.saskcropinsurance.com/maps/#

Saskatchewan Institute of Pedology. 1994. The Soils of Emerald, Rural Municipality No. 277, Saskatchewan. Saskatchewan Institute of Pedology, University of Saskatchewan, Saskatoon, Saskatchewan.

Saskatchewan Watershed Authority. 2003a. Rural Water Control Assistance Program. Saskatchewan Watershed Authority, Moose Jaw, Saskatchewan.

Saskatchewan Watershed Authority. 2003b. Technical Assistance for Private Drainage Works. Saskatchewan Watershed Authority, Moose Jaw, Saskatchewan.

Saskatchewan Wetland Conservation Corporation. 1993. The Economics of Converting Wetlands to Croplands. Farm Management Facts, Water Series. Saskatchewan Wetland Conservation Corporation, Regina, Saskatchewan.

Scodari, P.F. 1990. *Wetlands Protection: The Role of Economics*. Environmental Law Institute, Washington, D.C.

Sharpe, W.F., G.J. Alexander, J.V. Bailey, D.J. Fowler, and D.L. Domian. 2000. *Investments*. 3rd ed. Prentice Hall, Scarborough, Ontario.

Siemens, J., Hamburg, K., and Tyrell, T. 1990. A Farm Machinery Selection and Management Program. *Journal of Production Agriculture* 3(2), 212-219.

Snyder, G. H., Deren, C. W., and Glaz, B. 1999. Wetland Crops versus Wetland Drainage. *HortScience* 34(1), 46-49.

Statistics Canada. 2005. CANSIM Table 176-0043, Series v122558. Statistics Canada, Ottawa, Ontario.

Statistics Canada. 2004. Consumer Price Index, CANSIM Table 326-0002. Statistics Canada, Ottawa, Ontario.

Stavins, R. N. 1990. Alternative Renewable Resource Strategies: A Simulation of Optimal Use. *Journal of Environmental Economics and Management* 19, 143-159.

Stavins, R. N. 1989. Alternative Resource Strategies: A Simulation of Optimal Use. John F. Kennedy School of Government, Harvard University, Cambridge, Massachusetts.

Stavins, R. N. and A. B. Jaffe. 1988. Forested Wetland Depletion in the United States: An Analysis of Unintended Consequences of Federal Policy and Programs. Harvard

University, Cambridge, Massachusetts.

Swinton, S. M. and R. P. King. 1994. A bioeconomic model for weed management in corn and soybeans. *Agricultural Systems* 44(3), 313-335.

Taff, S. J. 1992. What is a Wetland Worth? Concepts and Issues in Economic Valuation. University of Minnesota, St. Paul, Minnesota.

Taylor, J. S., R. S. Gray, and K. A. Rosaasen. 1993. The Local Economic Impacts of the North American Waterfowl Management Plan in Saskatchewan. *Canadian Journal of Agricultrual Economics* 41, 419-427.

Taylor, L.O. 2003. The Hedonic Method. In: *A Primer on Nonmarket Valuation*. Edited by Champ, P.A., K.J. Boyle, and T.C. Brown. Kluwer Academic Publishers, Dordrecht, The Netherlands.

The Weather Network. 2005. Weather Statistics. Accessed January 26, 2005. http://www.theweathernetwork.ca/weather/stats/north_america.htm

Trigeorgis, L. 1999. *Real Options: Managerial Flexibility and Strategy in Resource Allocation*. The MIT Press, Cambridge, Massachusetts.

Turner, R.K., J.C.J.M. van den Bergh, and R. Brouwer. 2003. *Managing Wetlands*. Edward Elgar, Northampton, Massachusetts.

United States Council on Environmental Quality. 1973. Report on channel modifications. Washington, D.C.

United States Fish and Wildlife Service. 2003. Kulm Wetland Management District. Accessed October 20, 2004. http://kulmwetlands.fws.gov/pothole.html

van den Bergh, J.C.J.M. 1999. *Handbook of Environmental and Resource Economics*. Edward Elgar, Northampton, Massachusetts.

van Kooten, G. C. and A. Schmitz. 1992. Preserving Waterfowl Habitat on the Canadian Prairies: Economic Incentives versus Moral Suasion. *American Journal of Agricultural Economics* 74(1), 79-89.

van Vuuren, W. 1994. Profitability of Subsurface Drainage on Operator Owned and on Rented Land. Department of Agricultural Economics and Business, University of Guelph, Guelph, Ontario.

van Vuuren, W. and P. Roy. 1993. Private and social returns from wetland preservation versus those from wetland conversion. *Ecological Economics* 8, 289-305.

van Vuuren, W. and P. Ysselstein. 1986. Relationship between land tenure and soil productivity. *Canadian Journal of Soil Science* 66(2), 357-366.

Verbeek, M. 2004. *A Guide to Modern Econometrics.* 2nd ed. John Wiley & Sons Ltd., West Sussex, England.

Vlahos, K. 1997. Taking the risk out of uncertainty. In: *The Complete MBA Companion.* Edited by Dickson, T. and G. Bickerstaffe. Pitman Publishing, Lanham, Maryland.

Wanchuk, R. N. 1986. Economics of Farm Drainage. M. S. Thesis. Department of Rural Economy, University of Alberta, Edmonton, Alberta.

Willis, K. G., J. F. Benson, and C. M. Saunders. 1988. The Impact of Agricultural Policy on the Costs of Nature Conservation. *Land Economics* 64(2), 147-156.

Appendix A – Simple Wetland Valuation Methods

Valuation Method	Description
Market analysis	Used when market prices of outputs (and inputs) are available. It is the marginal productivity net of human effort/cost. One could approximate with market price of close substitutes. Requires the use of shadow pricing.
Productivity losses	The change in net return from marketed goods. It is a form of dose-response market analysis.
Production functions	The ecosystem is treated as one input into the production of other goods. It is based on ecological linkages and market analysis.
Public pricing	Public investment is used, for instance via land purchase or monetary incentives, as a surrogate for market transactions.
Damage costs avoided	The costs that would be incurred if the ecosystem function were not present, e.g. flood protection.
Defensive expenditures	Costs incurred in mitigating the effects of reduced environmental quality. Represents a minimum value for the environmental function.
Relocation costs	Expenditures involved in relocation of affected agents or facilities. This is a particular form of defensive expenditure.
Replacement/substitute costs	Potential expenditures incurred in replacing the function that is lost, for instance by the use of substitute facilities or 'shadow projects'.
Restoration costs	Costs of returning the degraded ecosystem to its original state. This is a total value approach and has important ecological, temporal and cultural dimensions.

Source: Turner et al. (2003)

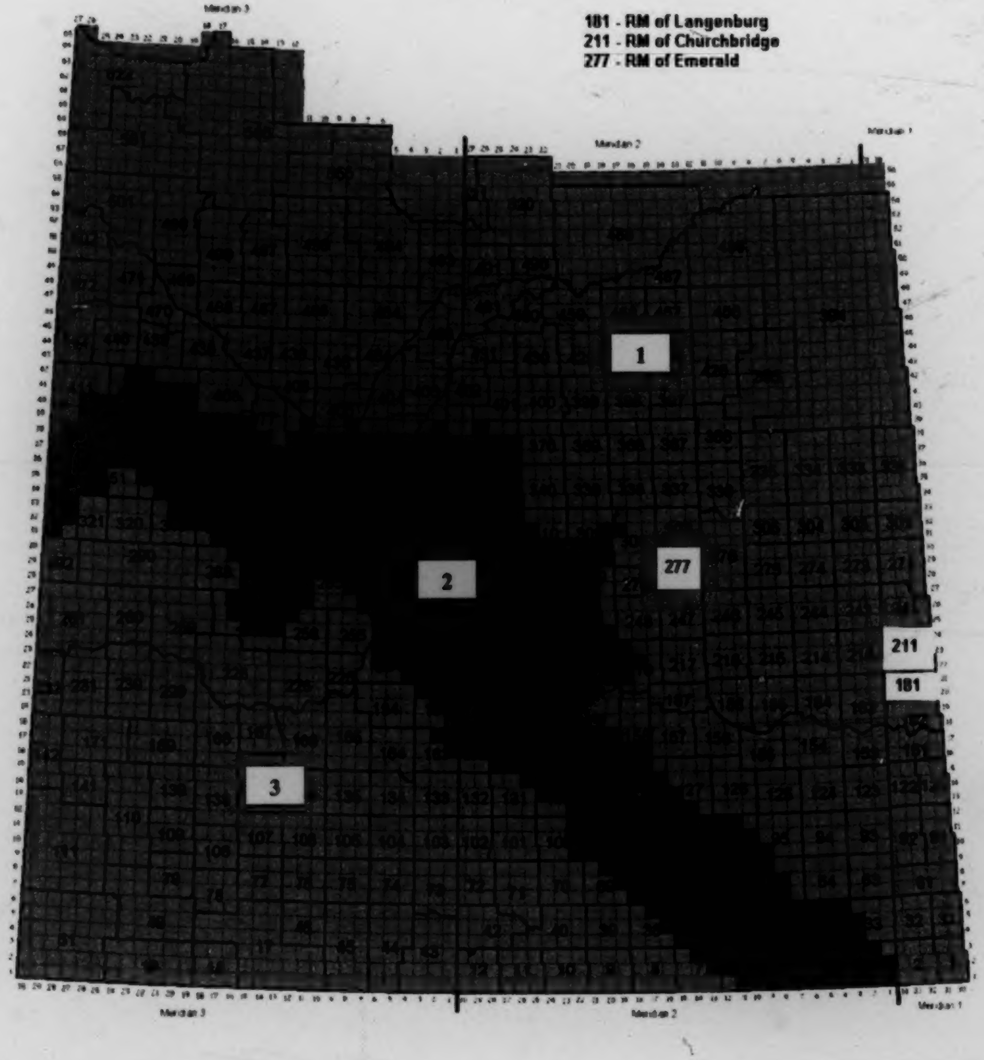
Appendix B – Saskatchewan Soil Survey Summary (1994)

Saskatchewan soil survey summary for the RM of Emerald (1994)

	Hectares		Hectares
Total Area	86,886	Surface pH (Soil Acidity)	
		X (< 5.5)	0
Soil Capability for Agriculture		*A (5.5 - 6.0)*	0
Class 1	1,066	*B (6.1 - 6.7)*	189
Class 2	33,803	*C (6.8 - 7.5)*	24,111
Class 3	27,089	*D (> 7.5)*	62,232
Class 4	5,434		
Class 5	13,839	Surface Texture	
Class 6	5,418	*Sands*	0
Class 7	236	*Sandy Loams*	62
Class O	0	*Loams*	86,340
		Clay Loams	130
Irrigation Suitability		*Clays*	0
Excellent	0	*Organics*	0
Good	2,991		
Fair	59,208	Wind Erosion Potential	
Poor	24,687	*Very Low*	36,591
		Low	49,879
Salinity		*Moderate*	62
Very Strong	0	*High*	0
Strong	352	*Very High*	0
Moderate	1,263	*Extremely High*	0
Weak	237		
None	85,034	Water Erosion Potential	
		Very Low	314
Sand and Gravel		*Low*	61,601
Sandy	32	*Moderate*	23,908
Sandy and Gravelly	2,416	*High*	387
Gravelly	112	*Very High*	322
Stones		Wetlands and Poorly Drained Soils	
Non- to Slightly Stony	46,072	*Open Water and Lakes*	233
Moderately Stony	40,020	*Wet, Poorly Drained Soils*	16,953
Very Stony	441		
Excessively Stony	0		

Source: Saskatchewan Institute of Pedology (1994)

Appendix C – Soil Zones of Saskatchewan


181 - RM of Langenburg
211 - RM of Churchbridge
277 - RM of Emerald
Meridian 3
Meridian 2
Meridian 1
1
2
3
277
211
181

Source: Saskatchewan Crop Insurance (2004)

Black/Grey	1
Dark Brown	2
Brown	3

Appendix D – Overview of Classification Methodology for Determining Land Capability for Agriculture

The CLI agriculture product shows the varying potential of a specific area for agricultural production. It indicates the classes and subclasses according to the Soil Capability Classification of Agriculture, which is based on characteristics of the soil as determined by soil surveys. The mineral soils are grouped into 7 classes and 13 subclasses according to the potential of each soil for the production of field crops. Organic soils are not a part of the classification and are shown as a single separate unit (0). Soils classes as 1, 2, 3, or 4 are considered capable of sustained use for cultivated field crops, those in classes 5 and 6 only for perennial forage crops and those in class 7 for neither.

These agricultural capability maps can be used at the regional level for making decisions on land improvement and farm consolidation, for developing land-use plans, and for preparing equitable land assessments.

Some of the important factors on which agricultural classification is based are: (1) The soils will be well managed and cropped, under a largely mechanized system. (2) Land requiring improvements, including clearing, that can be made economically by the farmer, is classed according to its limitations or hazards in use after the improvements have been made. Land requiring improvements beyond the means of the farmer is classed according to its present condition. (3) The following are not considered: distances to marker, kind of roads, location, size of farms, type of ownership, cultural patters, skill or resources of individual operations, and hazard of crop damage by storms. (4) The classification does not include capability of soils for trees, tree fruits, small fruits, ornamental plants, recreation, or wildlife. (5) The classes are based on the intensity, rather than kinds, of their limitations for agriculture. Each class includes many kinds of soil, and many of the soils in any class require unique management and treatment. (6) Land given a capability classification of 6 or 7 will never warrant irrigation since the benefits derived from irrigation would be negligible. For this reason, capability Classes 6 and 7 will always appear in the non-irrigated portion (Classes A to C) of a land unit classification.

Land Capability Class Descriptions for Agriculture

The classes indicate the degree of limitation imposed by the soil in its use for mechanized agriculture. The subclasses indicate the kinds of limitations that individually or in combination with others, are affecting agricultural land use.

Valid Classes

1. No significant limitations
2. Moderate limitations, moderate conservation practices required
3. Moderately severe limitations, range of crops restricted or special conservation practices required.
4. Severe limitations
5. Forage crops improvement practices feasible
6. Forage crops improvement practices not feasible
7. No capability for arable culture or permanent pasture

0. Organic soils
W. Water area
F. Forest reserves
N. National parks
U. Urban area
P. Provincial parks
?. Unmapped area

Valid Limitation Subclasses

C. Adverse climate
D. Undesirable soil structure and/or low permeability
E. Erosion
F. Low fertility
I. Inundation by streams or lakes
M. Moisture limitation
N. Salinity
P. Stoniness
R. Consolidated bedrock
S. Cumulative adverse soil characteristics
T. Topography limitation
W. Excess water
X. Cumulative minor adverse characteristics

Valid Irrigation Classes

Y. Irrigated component
N. Non-irrigated component

Class Descriptions

Class 1 - Soils in this class have no significant limitations in use for crops. The soils are deep, are well to imperfectly drained, hold moisture well, and in the irgin state were well supplied with plant nutrients. They can be managed and cropped without difficulty. Under good management they are moderately high to high in productivity for a wide range of field crops.

Class 2 - Soils in this class have moderate limitations that restrict the range of crops or require moderate conservation practices. The soils are deep and hold moisture will. The limitations are moderate and the soils can be managed and cropped with little difficulty. Under good management they are moderately high to high inproductivity for a fairly wide range of crops.

Class 3 - Soils in this class have moderately severe limitations that restrict the range of crops or require special conservation practices. The limitations are more severe than for class 2 soils. They affect one or more of the following practices: timing and ease of tillage, planting and harvesting, choice of crops, and methods of conservation. Under good management they are fair to moderately high in productivity for a fair range of crops.

Class 4 - Soils in this class have severe limitations that restrict the range of crops or require special conservation practices, or both. The limitations seriously affect one or more of the following practices: timing and ease of tillage, planting and harvesting, choice of crops, and methods of conservation. The soils are low to fair in productivity for a fair range of crops but may have high productivity for a specially adapted crop.

Class 5 - Soils in this class have very severe limitations that restrict their capability to producing perennial forage crops, and improvement practices are feasible. The limitations are so severe that soils are not capable of use for sustained production of annual field crops. The soils are capable of producing native or tame species of perennial forage plants, and may be improved by use of farm machinery. The improvement practices may include clearing of bush, cultivation, seeding, fertilizing, or water control.

Class 6 - Soils in this class are capable only of producing perennial forage crops, and improvement practices are not feasible. The soils provide some sustained grazing for farm animals, but the limitations are so sever that improvement by use of farm machinery is impractical terrain may be unsuitable for use of farm machinery, or the soils may not respond to improvement, or the grazing season may be very short.

Class 7 - Soils in this class have no capability for arable culture or permanent pasture. This class also includes rockland, other non-soil areas, and bodies of water too small to show on the maps.

Class 0 - Organic soils (not placed in capability classes).

Subclass Descriptions

'c' - Adverse Climate - this subclass denotes a significant adverse climate for crop production as 'median' climate which is defined as one with sufficiently high growing-season temperatures to bring crops to maturity.

'd' - Undesirable soil structure and/or low permeability - this subclass indicates soils that are difficult to till or soils where water is absorbed very slowly or where the depth of rooting zone is restricted by conditions other than a high water table or consolidated bedrock.

'e' - Erosion - this subclass includes soils where damage from erosion is a limitation to agricultural use. Damage is assessed on loss of productivity and on the difficulties in farming land with gullies.

'f' - Low Fertility - included are soils having low fertility that either is correctable with careful management in the use of fertilizers and soil amendments or is difficult to correct by any practical means. The limitations may be due to lack of plant nutrients, high acidity or alkalinity, low exchange capacity, high levels of carbonates or presence of toxic compounds.

'i' - Inundation by streams or lakes - this subclass includes soils subjected to inundation causing crop damage or restricting agricultural use.

'm' - Moisture Limitations - this consists of soils where crops are affected by drought owing to inherent soil characteristics. These soils usually have low water-holding capacity.

'n' - Salinity - soils of this subclass possess excessive soluble salts which adversely affect crop growth or restrict the range of crops that may be grown.

'p' - Stoniness - these soils are sufficiently stoney to hinder tillage, planting and harvesting operations.

'r' - Consolidated Bedrock - this subclass includes soils where the presence of bedrock near the surface restricts their agricultural use. Consolidated bedrock at depths greater than 3 feet from the surface is not considered as a limitation except on irrigated lands where a greater depth of soil is desirable.

's' - There are two interpretations accorded to subclass s. In the case of maps generally produced before 1969, subclass s will be used in place of subclasses d, f, m or n. If two or more of subclasses d, f, m or n are applicable to the same area, then again subclass s will be substituted. On most of the maps subsequent to 1969, the applicable subclass d,f, m or n will appear if an area is classified with a single subclass. For areas classified with two or more of d, f, m or n then subclass s will appear, denoting a combination of subclasses.

't' - Topography - this subclass is made up of soils where topography is a limitation. Both the percent of slope and the pattern or frequency of slopes in different directions affect the cost of farming and the uniformity of growth and maturity of crops as well as the hazard of erosion.

'w' - Excess Water - this subclass includes soils where excess water other than brought about by inundation is a limitation to agricultural use. Excess water may result from inadequate soil drainage, a high water table, seepage or from runoff from surrounding areas.

'x' - This subclass is comprised of soils having a limitation resulting from the cumulative effect of two or more adverse characteristics.

Appendix E – Census of Agriculture Data Summaries

Table E.1 – Selected Census of Agriculture statistics for the RM of Emerald for 1996 and 2001

				Average per Farm	
	1996	2001	% Change	1996	2001
Number of Farms	229	202	-12%		
Farm Land (ha)					
Area Owned	57,541	57,660	0%	251	285
Area Leased from Gov't	2,242	1,525	-32%	10	8
Area Rented	16,931	17,334	2%	74	86
Total Farm Area	76,715	76,519	0%	335	379
Crop Land (ha)					
Spring Wheat	21,470	16,191	-25%	94	80
Oats	4,359	6,822	57%	19	34
Barley	10,621	7,769	-27%	46	38
Canola	7,732	11,255	46%	34	56
Flax	2,308	3,122	35%	10	15
Alfalfa	575	1,781	210%	3	9
Field Peas	835	3,505	320%	4	17
Total Field Crops	50,672	53,056	5%	221	263
Summerfallow	14,384	10,932	-24%	63	54
Livestock					
Total Cattle	5,261	4,846	-8%	23	24
Total Poultry	51,420	61,391	19%	225	304
Total Swine	581	82	-86%	3	0

Source: Biggs (2004)

Table E.2 – Number of farms by farm type

	Number	% of Total
Cattle	28	14%
Cash Crop	162	80%
Other	12	6%

Source: Biggs (2004)

Table E.3 – Cash crop farms classified by sales

	Number	% of Total
< $50,000	74	46%
$50,000-100,000	44	27%
> $100,000	44	27%

Source: Biggs (2004)

Appendix F – Test Statistics for Testing for a Significant Difference between the Means of Simulations with 1,000 and 5,000 Iterations

Summary Statistic	Test Statistic
Yearly Cash Flow Without Drainage	-0.0331
Yearly Cash Flow With Drainage	0.0484
Initial Cropland Hectares	0.1304
Initial Wet Area Hectares	0.3848
20-year NPV Without Drainage	-0.0316
20-year NPV With Drainage	0.0503
20-year NPV Difference[a]	1.4939
20-year NPV Difference per Hectare Drained[a]	0.4914
Perpetuity NPV Without Drainage[b]	-0.0640
Perpetuity NPV With Drainage[b]	0.0252
Perpetuity NPV Difference[a, b]	1.4338
Perpetuity NPV Difference per Hectare Drained[a, b]	0.3313
Annual Incentive Payment ($/ha drained)	0.3313
Wetlands Drained (ha)	0.0965
Cropped Basins Drained (ha)	0.7324
Percent of Wet Areas Drained on Owned Land	-0.2163
Percent of Wet Areas Drained on Total Land Operated	0.0148
Number of Years to Drain a Quarter of Land	0.5154
PV of Cost of Drainage Conducted[c]	-1.6085
Initial Machinery Nuisance Cost Total for Farm[d]	0.0623
Initial Input Waste Nuisance Cost Total for Farm[d]	-0.0584
Initial Nuisance Costs as a percentage of Total Variable Costs	0.0030

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted. The difference in means was tested using a standard z-test for the difference between two sample means taken from Daniel and Terrell (1992). The 5% critical value used for testing was 1.96. Summary outputs for this test are available in Tables L.1 and L.2 in Appendix L.

Appendix G – Weather, Yield and Price Data

Table G.1 – Kelliher Weather Station Data 1953-2001

Year	Precipitation	Growing Degree Days	Water Ratio
	Growing Season (May 15 - August 13)	Growing Season (May 15 - August 13)	Water Use / Water Demand
1953	378.70	862.35	0.44
1954	278.20	846.36	0.33
1955	159.30	1022.01	0.16
1956	161.20	1067.46	0.15
1957	173.20	1021.85	0.17
1958	70.50	973.76	0.07
1959	130.10	1022.34	0.13
1960	196.10	1049.91	0.19
1961	44.90	1215.10	0.04
1962	196.00	997.51	0.20
1963	209.40	1027.89	0.20
1964	145.00	1023.96	0.14
1965	272.50	965.87	0.28
1966	225.20	977.56	0.23
1967	64.20	1003.11	0.06
1968	118.10	865.90	0.14
1969	241.60	830.18	0.29
1970	214.10	1105.03	0.19
1971	212.00	939.15	0.23
1972	109.70	981.21	0.11
1973	205.20	1003.26	0.20
1974	261.20	980.87	0.27
1975	136.80	1020.45	0.13
1976	286.90	1072.21	0.27
1977	124.70	1010.71	0.12
1978	191.60	1075.31	0.18
1979	69.70	1097.15	0.06
1980	202.60	1115.31	0.18
1981	253.50	1060.71	0.24
1982	174.10	978.34	0.18
1983	263.60	1055.34	0.25
1984	132.40	1099.84	0.12
1985	152.60	881.09	0.17
1986	156.80	1047.40	0.15
1987	235.20	1036.65	0.23
1988	116.30	1300.71	0.09
1989	166.20	1124.96	0.15
1990	181.50	1072.71	0.17
1991	210.70	1112.46	0.19
1992	163.50	865.35	0.19
1993	232.60	811.34	0.29
1994	274.80	973.90	0.28
1995	269.20	1052.15	0.26

1996	231.80	1008.71	0.23
1997	260.00	1114.78	0.23
1998	248.80	1085.09	0.23
1999	205.20	946.71	0.22
2000	264.20	1004.96	0.26
2001	142.00	1098.40	0.13

Source: Boychuk (2004)

Table G.2 – Crop Yield Data 1967-2002

	Crop Yields (tonne/ha)			
Year	Wheat	Barley	Canola	Flax
1967	1.21	1.18	1.12	0.75
1968	1.68	2.04	1.40	0.75
1969	2.08	2.37	1.24	0.94
1970	1.81	2.37	1.01	0.88
1971	2.08	2.80	1.12	1.07
1972	1.68	1.72	0.84	0.94
1973	2.01	2.42	0.73	0.94
1974	1.14	1.51	0.73	0.69
1975	1.68	1.77	0.90	0.88
1976	2.35	2.69	1.12	0.94
1977	1.68	2.15	1.12	0.94
1978	2.21	2.58	1.40	1.32
1979	1.21	1.34	0.62	0.63
1980	1.68	1.88	1.12	1.13
1981	2.35	2.96	1.46	1.38
1982	1.95	2.63	1.29	1.01
1983	1.97	2.26	1.38	1.19
1984	1.81	2.18	1.30	0.97
1985	2.44	3.35	1.60	1.35
1986	2.10	2.50	1.57	1.17
1987	1.88	2.82	1.52	1.21
1988	0.95	1.16	0.80	0.61
1989	1.86	2.21	0.89	0.84
1990	1.93	2.47	1.37	1.26
1991	2.05	2.40	0.96	1.25
1992	1.99	3.08	0.93	1.26
1993	1.52	3.13	1.04	1.57
1994	1.74	2.90	1.15	1.25
1995	1.85	2.71	0.72	1.07
1996	2.15	2.91	1.53	1.58
1997	1.87	2.26	1.13	1.25
1998	2.07	2.72	1.40	1.29
1999	2.03	2.45	1.51	1.03
2000	2.01	2.49	1.60	1.23
2001	1.52	1.49	1.15	0.84
2002	1.29	1.92	1.01	1.08

Source: Saskatchewan Agriculture, Food and Rural Revitalization (2004c)

Table G.3 – Commodity Prices 1960-2002

	CPI Deflated Crop Year Prices ($/tonne)			
Year	Flax	Barley	Canola	Wheat
1960	720.58	237.99	469.37	383.43
1961	863.29	313.93	503.59	398.95
1962	789.45	271.78	582.38	388.25
1963	738.90	280.27	700.68	414.04
1964	717.58	293.27	755.02	368.15
1965	654.31	293.52	648.19	379.13
1966	629.14	282.23	635.02	382.19
1967	688.29	221.85	489.20	335.61
1968	622.42	196.55	442.25	262.07
1969	527.88	162.02	517.42	245.65
1970	434.62	181.93	525.59	272.90
1971	427.31	147.35	466.61	245.58
1972	735.67	262.41	665.39	295.21
1973	1571.19	504.87	1092.43	696.37
1974	1474.68	393.25	1223.00	589.87
1975	918.14	379.31	783.43	450.21
1976	886.76	296.68	886.76	346.13
1977	660.42	238.49	874.45	317.98
1978	793.83	232.82	791.02	401.12
1979	773.37	287.76	688.58	454.77
1980	800.55	343.09	658.18	483.13
1981	676.91	272.01	589.70	392.44
1982	470.10	202.27	505.68	322.14
1983	571.68	221.24	679.64	315.04
1984	532.62	212.03	593.69	296.84
1985	420.71	176.11	423.97	218.51
1986	267.78	129.97	311.62	164.42
1987	301.62	123.05	391.66	172.57
1988	510.54	187.49	428.34	263.93
1989	468.59	163.52	362.78	208.87
1990	246.44	114.04	329.02	150.74
1991	185.00	119.20	290.54	140.30
1992	251.94	110.07	310.64	145.54
1993	260.70	100.92	362.82	142.96
1994	317.74	139.09	417.26	200.24
1995	341.55	199.53	429.58	251.17
1996	374.18	146.67	453.86	183.62
1997	378.49	142.08	430.78	169.36
1998	328.84	117.12	389.65	168.92
1999	221.36	120.64	272.27	139.46
2000	246.76	126.07	262.92	150.85
2001	321.51	147.10	335.17	174.41
2002	378.21	157.24	327.85	183.96

Source: Saskatchewan Agriculture, Food and Rural Revitalization (2004a)

Appendix H – J-test Results

Table H.1 – J-test Results - Kelliher Weather Station

Variable	Canola	Barley	Flax	Wheat
	Estimated Coefficient	Estimated Coefficient	Estimated Coefficient	Estimated Coefficient
GS/GDD	5.2899	20.0020***	8.2014**	14.7830***
	(4.8553)	(6.5439)	(3.1715)	(4.6814)
$(GS/GDD)^2$	-13.1240	-42.8060**	-17.3560**	-35.8710***
	(12.5880)	(16.3020)	(8.1475)	(11.7330)
Y^*	0.6310	0.2719	0.1406	0.3470
	(0.5269)	(0.3090)	(0.4596)	(0.3114)
Constant	-0.0493	-0.3847	0.0543	-0.1677
	(0.4789)	(0.5886)	0.4200	0.4144
Std. Error	0.2653	0.3869	0.2015	0.2471
R^2	0.1944	0.5598	0.3918	0.5231

Notes: y* variable represents predicted yield values from the Wynyard weather station equation. * represents significance at the 10% level, ** at the 5% level and * at the 1% level. Standard errors are in brackets.**

Table H.2 – J-test Results - Wynyard Weather Station

Variable	Canola	Barley	Flax	Wheat
	Estimated Coefficient	Estimated Coefficient	Estimated Coefficient	Estimated Coefficient
GS/GDD	4.8929	--2.5286	-5.4904	4.8817
	(4.5646)	(6.8095)	(3.4352)	(4.3406)
$(GS/GDD)^2$	-13.0640	10.1520	13.9860*	-11.8600
	(11.0770)	(15.7600)	(7.9511)	(10.4200)
y^*	0.6825	0.9320***	1.2645***	0.8155***
	(0.5730)	(0.2597)	(0.3506)	(0.2564)
Constant	-0.0394	0.2515	0.2002	-0.1092
	(0.4823)	(0.4615)	(0.2564)	(0.3414)
Std. Error	0.2645	0.3796	0.1915	0.2469
R^2	0.1992	0.5764	0.4512	0.5239

Notes: y* variable represents predicted yield values from the Kelliher weather station equation. * represents significance at the 10% level, ** at the 5% level and * at the 1% level. Standard errors are in brackets.**

The predicted values (y*) from the yield equations that used Wynyard weather station data were not significant in the yield equations that used Kelliher weather station data and the predicted values (y*) from the yield equations that used the Kelliher weather station data were significant in the yield equations that used the Wynyard weather station data, indicating that the model with the Kelliher weather station data was more appropriate.

Appendix I – Autocorrelation Functions

Figure I.1 – Autocorrelation Function Canola Price Series

```
           -1.0      -0.8      -0.6      -0.4      -0.2       0.0       0.2       0.4       0.6       0.8       1.0
             *.........*.........*.........*.........*.........*.........*.........*.........*.........*.........*
  1  0.8462  .                                  +              RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR       .
  2  0.6249  .                         +                       RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR                  .
  3  0.4970  .                     +                           RRRRRRRRRRRRRRRRRRRRRRRRRR  +                     .
  4  0.4294  .                   +                             RRRRRRRRRRRRRRRRRRRRRR        +                   .
  5  0.3323  .                  +                              RRRRRRRRRRRRRRRRRR             +                  .
  6  0.2709  .                 +                               RRRRRRRRRRRRRRR                 +                 .
  7  0.2543  .                +                                RRRRRRRRRRRRRR                   +                .
  8  0.2207  .                +                                RRRRRRRRRRRR                     +                .
  9  0.2067  .                +                                RRRRRRRRRRR                      +                .
 10  0.1833  .               +                                 RRRRRRRRRR                        +               .
 11  0.0786  .               +                                 RRRRR                             +               .
 12 -0.0623  .               +                              RRRR                                 +               .
 13 -0.1092  .               +                            RRRRRR                                 +               .
 14 -0.1105  .               +                           RRRRRRR                                 +               .
 15 -0.1778  .               +                        RRRRRRRRRR                                 +               .
 16 -0.2799  .               +                   RRRRRRRRRRRRRRR                                 +               .
```

Figure I.2 – Autocorrelation Function Barley Price Series

```
           -1.0      -0.8      -0.6      -0.4      -0.2       0.0       0.2       0.4       0.6       0.8       1.0
             *.........*.........*.........*.........*.........*.........*.........*.........*.........*.........*
  1  0.8177  .                                  +              RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR        .
  2  0.5903  .                         +                       RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR                   .
  3  0.4559  .                      +                          RRRRRRRRRRRRRRRRRRRRRRRR   +                      .
  4  0.3585  .                    +                            RRRRRRRRRRRRRRRRRRR          +                    .
  5  0.3230  .                   +                             RRRRRRRRRRRRRRRRR             +                   .
  6  0.3288  .                  +                              RRRRRRRRRRRRRRRRR              +                  .
  7  0.3401  .                  +                              RRRRRRRRRRRRRRRRRR             +                  .
  8  0.2731  .                 +                               RRRRRRRRRRRRRRR                 +                 .
  9  0.1782  .                +                                RRRRRRRRRR                       +                .
 10  0.1037  .                +                                RRRRRR                           +                .
 11  0.0636  .                +                                RRRR                             +                .
 12  0.0166  .                +                                RR                               +                .
 13 -0.0318  .                +                              RRR                                +                .
 14 -0.0347  .                +                              RRR                                +                .
 15 -0.0372  .                +                              RRR                                +                .
 16 -0.1164  .                +                          RRRRRRR                                +                .
```

Figure I.3 – Autocorrelation Function Flax Price Series

```
          -1.0      -0.8      -0.6      -0.4      -0.2       0.0       0.2       0.4       0.6       0.8       1.0
            *.........*.........*.........*.........*.........*.........*.........*.........*.........*.........*
  1  0.8399 .                                  +              RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR       .
  2  0.5979 .                         +                       RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR                   .
  3  0.4726 .                      +                          RRRRRRRRRRRRRRRRRRRRRRRRR  +                      .
  4  0.4698 .                    +                            RRRRRRRRRRRRRRRRRRRRRRRR     +                    .
  5  0.4702 .                  +                              RRRRRRRRRRRRRRRRRRRRRRRRR      +                  .
  6  0.4218 .                +                                RRRRRRRRRRRRRRRRRRRRRR           +                .
  7  0.3665 .               +                                 RRRRRRRRRRRRRRRRRRR               +               .
  8  0.3065 .              +                                  RRRRRRRRRRRRRRRR                   +              .
  9  0.2337 .              +                                  RRRRRRRRRRRRR                      +              .
 10  0.1402 .             +                                   RRRRRRRR                            +             .
 11  0.0674 .             +                                   RRRR                                +             .
 12  0.0299 .             +                                   RR                                  +             .
 13  0.0094 .             +                                   R                                   +             .
 14 -0.0133 .             +                                  RR                                   +             .
 15 -0.0571 .             +                                RRRR                                   +             .
 16 -0.1433 .             +                            RRRRRRRR                                   +             .
```

Figure I.4 – Autocorrelation Function Wheat Price Series

```
          -1.0      -0.8      -0.6      -0.4      -0.2       0.0       0.2       0.4       0.6       0.8       1.0
            *.........*.........*.........*.........*.........*.........*.........*.........*.........*.........*
  1  0.8413 .                                  +              RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR       .
  2  0.6285 .                         +                       RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR                  .
  3  0.5099 .                     +                           RRRRRRRRRRRRRRRRRRRRRRRRRR  +                     .
  4  0.4453 .                   +                             RRRRRRRRRRRRRRRRRRRRRRR       +                   .
  5  0.4181 .                  +                              RRRRRRRRRRRRRRRRRRRRRR         +                  .
  6  0.4074 .                +                                RRRRRRRRRRRRRRRRRRRRR            +                .
  7  0.3757 .               +                                 RRRRRRRRRRRRRRRRRRRR              +               .
  8  0.2863 .              +                                  RRRRRRRRRRRRRRR                    +              .
  9  0.1991 .              +                                  RRRRRRRRRRR                        +              .
 10  0.1353 .             +                                   RRRRRRRR                            +             .
 11  0.0384 .             +                                   RRR                                 +             .
 12 -0.0233 .             +                                  RR                                   +             .
 13 -0.0172 .             +                                  RR                                   +             .
 14 -0.0011 .             +                                   R                                   +             .
 15 -0.0328 .             +                                 RRR                                   +             .
 16 -0.1369 .             +                            RRRRRRRR                                   +             .
```

Appendix J – Additional Machinery Cost Summaries

Table J.1 – Deflated machinery costs per hectare by farm size and field operation

	Number of Quarter Sections				
Operation	4	8	12	16	20
Seeding	16.40	13.92	13.48	9.88	9.88
Spraying	4.15	3.13	2.86	2.45	2.45
Swathing	10.08	5.71	4.57	6.98	6.02
Combining	16.07	16.07	13.18	11.15	10.47

Note: Costs for each operation include operating costs for tractors where applicable.

Source: Saskatchewan Agriculture, Food and Rural Revitalization (2004d)

Table J.2 – Deflated total machinery costs for cropping and fallow operations by farm size

	Number of Quarter Sections				
	4	8	12	16	20
Cropping	51.88	42.75	37.66	33.52	31.88
Fallow	12.44	9.40	8.58	7.34	7.34

Source: Saskatchewan Agriculture, Food and Rural Revitalization (2004d)

Appendix K – Approximate Field Configurations for Nuisance Cost Calculations (Desjardins, 1983)

Figure K.1 – Approximate configuration of one wetland within a quarter section

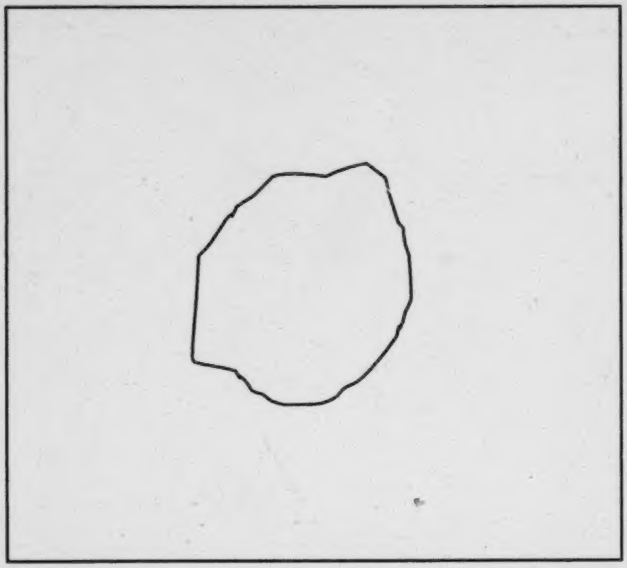


Figure K.2 – Approximate configuration of four wetlands within a quarter section

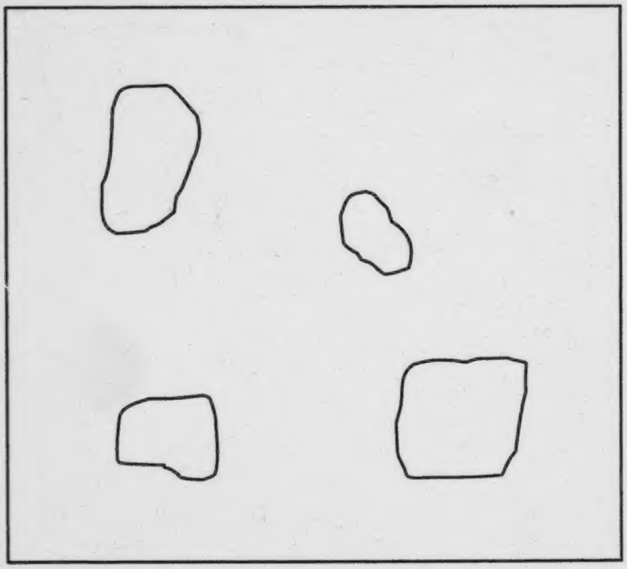


Figure K.3 – Approximate configuration of a circular obstacle located in the center of a quarter section

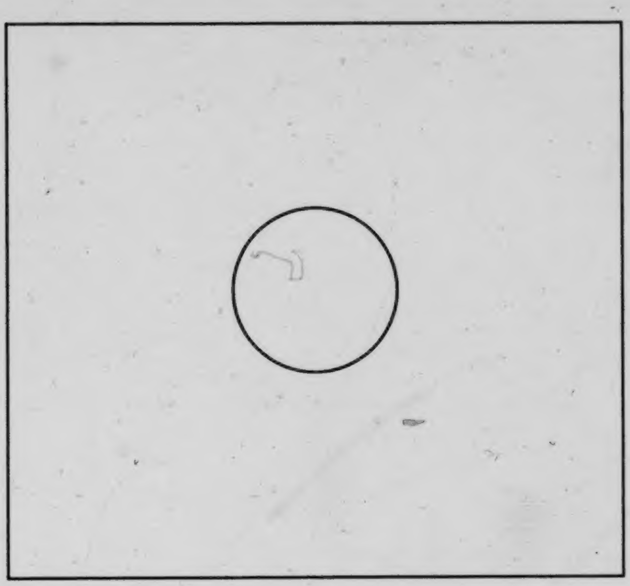


Figure K.4 – Approximate configuration of a circular obstacle located in the corner of a quarter section

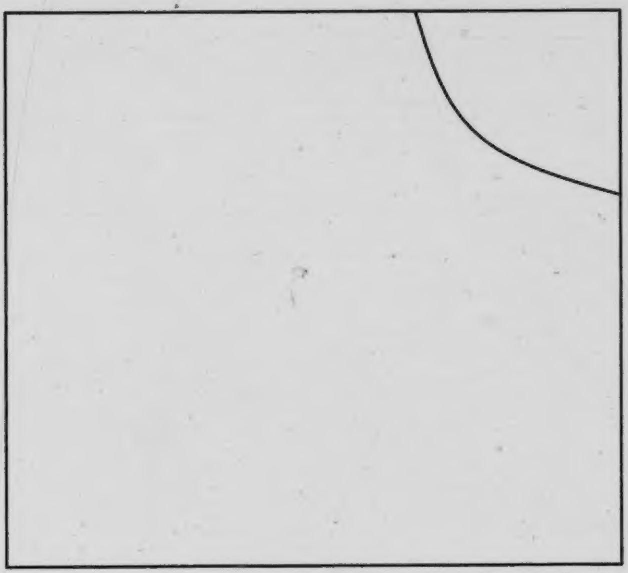
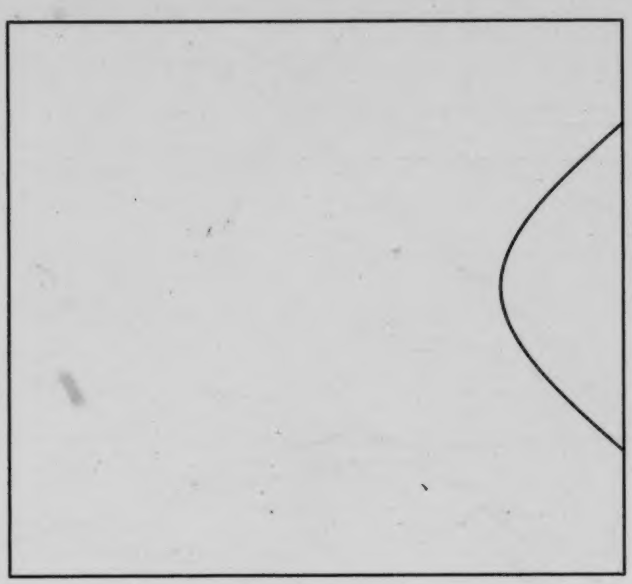


Figure K.5 – Approximate configuration of a circular obstacle located along the side of a quarter section



Appendix L – Summary Statistics Tables

Table L.1 – Summary statistics for a representative farm comprised of eight quarter sections that purchased a scraper to conduct drainage relative to performing no drainage (1,000 iterations)

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$60,240	$17,323	$34,288	$91,141	$12,900	$117,101
Yearly Cash Flow With Drainage	$60,854	$17,819	$34,156	$92,143	$12,900	$119,864
Initial Cropland Hectares	451.61	12.48	429.72	471.60	405.22	482.49
Initial Wet Area Hectares	77.54	12.08	59.22	97.80	43.21	128.62
20-year NPV Without Drainage	$563,818	$166,323	$315,986	$866,559	$115,689	$1,164,078
20-year NPV With Drainage	$553,183	$167,843	$304,877	$851,666	$85,882	$1,193,396
20-year NPV Difference[a]	-$10,635	$9,230	-$24,290	$3,423	-$51,815	$37,821
20-year NPV Difference per Hectare Drained[a]	-$552	$686	-$1,846	$112	-$5,982	$615
Percentage of Iterations where 20-year NPV was Positive	8.80%					
Perpetuity NPV Without Drainage[b]	$662,494	$185,249	$382,269	$995,553	$178,657	$1,314,535
Perpetuity NPV With Drainage[b]	$657,090	$189,368	$369,125	$1,001,262	$153,330	$1,359,040
Perpetuity NPV Difference[a, b]	-$5,404	$11,677	-$20,053	$16,424	-$45,967	$48,318
Perpetuity NPV Difference[a, b] per Hectare Drained	-$384	$693	-$1,711	$384	-$5,749	$933
Percentage of Iterations where Perpetuity NPV was Positive	22.00%					
Annual Incentive Payment ($/ha drained)	-$38	$69	-$171	$38	-$575	$93
Wetlands Drained (ha)	24.09	20.03	0.00	60.69	0.00	119.02
Cropped Basins Drained (ha)	4.65	5.23	0.00	15.34	0.00	40.72
Percent of Wet Area Drained on Owned Land	48.07%	26.22%	0.00%	89.25%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	36.42%	20.27%	0.00%	69.80%	0.00%	85.03%
Number Years to Drain a Quarter of Land	3.11	0.23	3.00	3.60	3.00	4.50
PV of Cost of Drainage Conducted[b]	$482	$214	$0	$819	$0	$1,069
Initial Machinery Nuisance Cost Total for Farm[c]	$1,590	$75	$1,494	$1,720	$880	$1,933
Initial Input Waste Nuisance Cost Total for Farm[c]	$536	$22	$504	$579	$474	$650
Initial Nuisance Costs as a percentage of Total Variable Costs	2.51%	0.08%	2.46%	2.70%	1.94%	2.99%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a

hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.2 – Summary statistics for a representative farm comprised of eight quarter sections that purchased a scraper to conduct drainage relative to performing no drainage (5,000 iterations)

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$60,260	$17,597	$33,226	$90,916	$5,359	$139,206
Yearly Cash Flow With Drainage	$60,824	$18,083	$33,385	$91,981	$5,359	$139,662
Initial Cropland Hectares	451.55	12.35	430.37	470.95	396.23	494.30
Initial Wet Area Hectares	77.38	11.85	59.33	98.06	35.34	129.54
20-year NPV Without Drainage	$564,001	$168,794	$312,369	$856,674	$77,884	$1,363,498
20-year NPV With Drainage	$552,890	$170,181	$297,451	$848,582	$38,254	$1,346,715
20-year NPV Difference[a]	-$11,111	$9,004	-$24,959	$2,846	-$50,488	$40,265
20-year NPV Difference per Hectare Drained[a]	-$564	$636	-$1,712	$66	-$6,130	$839
Percentage of Iterations where 20-year NPV was Positive	7.82%					
Perpetuity NPV Without Drainage[b]	$662,906	$188,527	$375,897	$992,019	$107,616	$1,532,288
Perpetuity NPV With Drainage[b]	$656,925	$192,499	$365,633	$993,747	$98,523	$1,530,574
Perpetuity NPV Difference[a, b]	-$5,981	$11,377	-$21,153	$14,479	-$55,796	$69,631
Perpetuity NPV Difference[a, b] per Hectare Drained	-$392	$644	-$1,535	$360	-$5,881	$1,286
Percentage of Iterations where Perpetuity NPV was Positive	22.30%					
Annual Incentive Payment ($/ha drained)	-$39	$64	-$154	$36	-$588	$129
Wetlands Drained (ha)	24.02	19.88	0.00	61.12	0.00	132.86
Cropped Basins Drained (ha)	4.52	4.89	0.00	14.50	0.00	45.24
Percent of Wet Area Drained on Owned Land	48.27%	25.16%	0.00%	88.99%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	36.41%	19.44%	0.00%	68.62%	0.00%	88.01%
Number Years to Drain a Quarter of Land	3.10	0.23	3.00	3.60	3.00	5.50
PV of Cost of Drainage Conducted[b]	$494	$212	$0	$835	$0	$1,256
Initial Machinery Nuisance Cost Total for Farm[c]	$1,590	$76	$1,494	$1,722	$754	$1,933
Initial Input Waste Nuisance Cost Total for Farm[c]	$536	$23	$505	$580	$456	$653
Initial Nuisance Costs as a percentage of Total Variable Costs	2.51%	0.08%	2.46%	2.70%	1.77%	2.99%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.3 - Summary statistics for a representative farm comprised of eight quarter sections that rented a scraper to conduct drainage relative to performing no drainage

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$60,240	$17,323	$34,288	$91,141	$12,900	$117,101
Yearly Cash Flow With Drainage	$61,074	$17,671	$34,615	$92,501	$12,900	$119,668
Initial Cropland Hectares	451.61	12.48	429.72	471.60	405.22	482.49
Initial Wet Area Hectares	77.54	12.08	59.22	97.80	43.21	128.62
20-year NPV Without Drainage	$563,818	$166,323	$315,986	$866,559	$115,689	$1,164,078
20-year NPV With Drainage	$566,113	$168,075	$320,492	$872,922	$115,689	$1,206,885
20-year NPV Difference[a]	$2,294	$7,165	-$7,119	$14,447	-$43,581	$42,807
20-year NPV Difference per Hectare Drained[a]	$126	$335	-$386	$740	-$1,057	$1,502
Percentage of Iterations where 20-year NPV was Positive	52.70%					
Perpetuity NPV Without Drainage[b]	$662,494	$185,249	$382,269	$995,553	$178,657	$1,314,535
Perpetuity NPV With Drainage[b]	$667,794	$188,358	$382,420	$1,001,678	$178,657	$1,369,690
Perpetuity NPV Difference[a, b]	$5,300	$9,376	-$5,238	$22,246	-$44,750	$55,156
Perpetuity NPV Difference[a, b] per Hectare Drained	$280	$431	-$307	$1,043	-$931	$1,876
Percentage of Iterations where Perpetuity NPV was Positive	61.00%					
Annual Incentive Payment ($/ha drained)	$28	$43	-$31	$104	-$93	$188
Wetlands Drained (ha)	13.09	14.87	0.00	35.66	0.00	111.68
Cropped Basins Drained (ha)	2.65	4.15	0.00	11.75	0.00	29.13
Percent of Wet Area Drained on Owned Land	26.43%	21.26%	0.00%	65.26%	0.00%	90.41%
Percent of Wet Area Drained on Total Land Operated	20.05%	16.43%	0.00%	50.92%	0.00%	76.22%
Number Years to Drain a Quarter of Land	3.01	0.08	3.00	3.00	3.00	4.00
PV of Cost of Drainage Conducted[b]	$427	$291	$0	$867	$0	$1,392
Initial Machinery Nuisance Cost Total for Farm[c]	$1,590	$75	$1,494	$1,720	$880	$1,933
Initial Input Waste Nuisance Cost Total for Farm[c]	$536	$22	$504	$579	$474	$650
Initial Nuisance Costs as a percentage of Total Variable Costs	2.51%	0.08%	2.46%	2.70%	1.94%	2.99%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.4 - Summary statistics for a representative farm comprised of eight quarter sections that already owned a scraper and conducted additional drainage relative to performing no additional drainage

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$58,895	$17,328	$32,867	$89,636	$11,730	$115,123
Yearly Cash Flow With Drainage	$60,273	$17,843	$33,440	$91,536	$11,730	$118,545
Initial Cropland Hectares	451.61	12.48	429.72	471.60	405.22	482.49
Initial Wet Area Hectares	77.54	12.08	59.22	97.80	43.21	128.62
20-year NPV Without Drainage	$551,221	$166,340	$303,695	$854,302	$100,373	$1,147,500
20-year NPV With Drainage	$555,337	$168,696	$306,533	$854,497	$87,456	$1,193,071
20-year NPV Difference[a]	$4,116	$9,060	-$8,412	$20,028	-$34,829	$54,946
20-year NPV Difference per Hectare Drained[a]	$140	$300	-$329	$690	-$783	$1,333
Percentage of Iterations where 20-year NPV was Positive	64.60%					
Perpetuity NPV Without Drainage[b]	$647,697	$185,271	$369,827	$980,370	$162,269	$1,295,063
Perpetuity NPV With Drainage[b]	$657,086	$190,070	$370,743	$999,973	$152,230	$1,355,908
Perpetuity NPV Difference[a, b]	$9,389	$12,197	-$5,010	$32,790	-$28,921	$65,443
Perpetuity NPV Difference[a, b] per Hectare Drained	$314	$373	-$217	$989	-$777	$1,744
Percentage of Iterations where Perpetuity NPV was Positive	76.80%					
Annual Incentive Payment ($/ha drained)	$31	$37	-$22	$99	-$78	$174
Wetlands Drained (ha)	23.91	20.33	0.00	59.92	0.00	119.02
Cropped Basins Drained (ha)	4.60	5.15	0.00	15.31	0.00	40.04
Percent of Wet Area Drained on Owned Land	47.70%	25.99%	0.00%	88.95%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	36.13%	20.10%	0.00%	68.70%	0.00%	85.03%
Number Years to Drain a Quarter of Land	3.19	0.34	3.00	4.00	3.00	5.00
PV of Cost of Drainage Conducted[b]	$475	$210	$0	$807	$0	$1,049
Initial Machinery Nuisance Cost Total for Farm[c]	$1,590	$75	$1,494	$1,720	$880	$1,933
Initial Input Waste Nuisance Cost Total for Farm[c]	$536	$22	$504	$579	$474	$650
Initial Nuisance Costs as a percentage of Total Variable Costs	2.51%	0.08%	2.46%	2.70%	1.94%	2.99%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.5 - Summary statistics for a representative farm comprised of eight quarter sections that purchased a scraper to conduct drainage relative to performing no drainage that drained only wetlands and not cropped basins

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$60,240	$17,323	$34,288	$91,141	$12,900	$117,101
Yearly Cash Flow With Drainage	$61,094	$18,038	$34,264	$92,786	$12,900	$119,565
Initial Cropland Hectares	451.61	12.48	429.72	471.60	405.22	482.49
Initial Wet Area Hectares	63.72	12.60	43.62	85.08	33.96	110.47
20-year NPV Without Drainage	$563,818	$166,323	$315,986	$866,559	$115,689	$1,164,078
20-year NPV With Drainage	$552,161	$169,681	$305,478	$861,312	$86,086	$1,177,353
20-year NPV Difference[a]	-$11,657	$9,511	-$24,899	$3,863	-$56,180	$39,014
20-year NPV Difference per Hectare Drained[a]	-$676	$1,180	-$2,002	$103	-$21,763	$632
Percentage of Iterations where 20-year NPV was Positive	9.50%					
Perpetuity NPV Without Drainage[b]	$662,494	$185,249	$382,269	$995,553	$178,657	$1,314,535
Perpetuity NPV With Drainage[b]	$656,929	$191,162	$370,356	$1,001,568	$154,588	$1,344,366
Perpetuity NPV Difference[a, b]	-$5,565	$12,425	-$21,394	$16,680	-$52,485	$61,619
Perpetuity NPV Difference[a, b] per Hectare Drained	-$468	$1,175	-$1,813	$429	-$21,097	$1,060
Percentage of Iterations where Perpetuity NPV was Positive	26.30%					
Annual Incentive Payment ($/ha drained)	-$47	$117	-$181	$43	-$2,110	$106
Wetlands Drained (ha)	29.28	19.68	6.17	64.85	0.00	108.65
Cropped Basins Drained (ha)	0.00	0.00	0.00	0.00	0.00	0.00
Percent of Wet Area Drained on Owned Land	59.63%	25.34%	14.97%	100.00%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	45.28%	20.14%	11.19%	76.49%	0.00%	90.70%
Number Years to Drain a Quarter of Land	3.08	0.19	3.00	3.50	3.00	4.50
PV of Cost of Drainage Conducted[b]	$604	$221	$336	$934	$0	$2,791
Initial Machinery Nuisance Cost Total for Farm[c]	$1,590	$75	$1,494	$1,720	$880	$1,933
Initial Input Waste Nuisance Cost Total for Farm[c]	$536	$22	$504	$579	$474	$650
Initial Nuisance Costs as a percentage of Total Variable Costs	2.51%	0.08%	2.46%	2.70%	1.94%	2.99%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.6 – Summary statistics for a representative farm comprised of four quarter sections that purchased a scraper to conduct drainage relative to performing no drainage

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$28,492	$8,861	$15,046	$44,134	$4,340	$58,468
Yearly Cash Flow With Drainage	$28,486	$9,051	$14,879	$44,440	$4,340	$58,644
Initial Cropland Hectares	225.59	8.83	210.07	239.44	192.14	245.88
Initial Wet Area Hectares	39.01	8.63	26.02	53.80	16.60	78.71
20-year NPV Without Drainage	$267,259	$84,638	$138,694	$420,631	$35,099	$570,768
20-year NPV With Drainage	$257,453	$84,343	$127,276	$408,665	$35,099	$565,404
20-year NPV Difference[a]	-$9,806	$7,688	-$21,143	$0	-$40,495	$13,608
20-year NPV Difference per Hectare Drained[a]	-$761	$836	-$2,178	$0	-$6,066	$437
Percentage of Iterations where 20-year NPV was Positive	2.80%					
Perpetuity NPV Without Drainage[b]	$314,058	$94,597	$174,276	$487,343	$58,450	$643,881
Perpetuity NPV With Drainage[b]	$306,715	$95,661	$164,777	$480,480	$58,450	$644,187
Perpetuity NPV Difference[a, b]	-$7,343	$7,979	-$19,689	$3,245	-$37,998	$30,709
Perpetuity NPV Difference[a, b] per Hectare Drained	-$626	$812	-$1,995	$142	-$5,773	$708
Percentage of Iterations where Perpetuity NPV was Positive	9.00%					
Annual Incentive Payment ($/ha drained)	-$63	$81	-$199	$14	-$577	$71
Wetlands Drained (ha)	11.87	12.90	0.00	29.14	0.00	95.57
Cropped Basins Drained (ha)	2.28	3.45	0.00	7.22	0.00	31.60
Percent of Wet Area Drained on Owned Land	46.82%	33.11%	0.00%	100.00%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	35.22%	25.43%	0.00%	77.48%	0.00%	95.63%
Number Years to Drain a Quarter of Land	3.01	0.08	3.00	3.00	3.00	4.00
PV of Cost of Drainage Conducted[b]	$413	$285	$0	$868	$0	$1,373
Initial Machinery Nuisance Cost Total for Farm[c]	$950	$62	$871	$1,064	$481	$1,332
Initial Input Waste Nuisance Cost Total for Farm[c]	$266	$16	$245	$298	$222	$374
Initial Nuisance Costs as a percentage of Total Variable Costs	2.47%	0.11%	2.42%	2.68%	1.72%	3.41%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.7 – Summary statistics for a representative farm comprised of 12 quarter sections that purchased a scraper to conduct drainage relative to performing no drainage

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$92,857	$25,791	$53,359	$138,901	$22,696	$174,017
Yearly Cash Flow With Drainage	$94,182	$26,835	$54,204	$142,042	$21,685	$182,994
Initial Cropland Hectares	677.22	15.23	651.12	700.91	613.89	720.73
Initial Wet Area Hectares	116.24	14.55	93.44	141.37	79.37	180.95
20-year NPV Without Drainage	$867,117	$247,246	$499,100	$1,310,984	$202,888	$1,760,049
20-year NPV With Drainage	$851,257	$251,367	$478,133	$1,305,137	$169,964	$1,810,632
20-year NPV Difference[a]	-$15,860	$12,902	-$33,516	$6,061	-$62,924	$50,583
20-year NPV Difference per Hectare Drained[a]	-$511	$649	-$1,480	$95	-$8,433	$634
Percentage of Iterations where 20-year NPV was Positive	10.00%					
Perpetuity NPV Without Drainage[b]	$1,019,333	$275,157	$588,449	$1,520,717	$297,803	$1,989,197
Perpetuity NPV With Drainage[b]	$1,013,019	$283,761	$575,260	$1,533,458	$274,550	$2,067,230
Perpetuity NPV Difference[a, b]	-$6,314	$17,452	-$28,062	$26,645	-$55,615	$79,433
Perpetuity NPV Difference[a, b] per Hectare Drained	-$318	$667	-$1,382	$394	-$8,176	$978
Percentage of Iterations where Perpetuity NPV was Positive	28.70%					
Annual Incentive Payment ($/ha drained)	-$32	$67	-$138	$39	-$818	$98
Wetlands Drained (ha)	40.20	25.45	9.59	88.34	0.00	157.15
Cropped Basins Drained (ha)	7.68	6.59	0.40	20.32	0.00	49.43
Percent of Wet Area Drained on Owned Land	54.22%	22.66%	16.08%	89.39%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	40.81%	17.43%	12.05%	68.18%	0.00%	84.96%
Number Years to Drain a Quarter of Land	3.12	0.20	3.00	3.50	3.00	4.33
PV of Cost of Drainage Conducted[b]	$529	$166	$279	$800	$0	$1,150
Initial Machinery Nuisance Cost Total for Farm[c]	$2,472	$95	$2,352	$2,626	$1,464	$2,766
Initial Input Waste Nuisance Cost Total for Farm[c]	$945	$31	$901	$1,003	$855	$1,059
Initial Nuisance Costs as a percentage of Total Variable Costs	2.85%	0.06%	2.80%	2.97%	2.23%	3.18%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.8 – Summary statistics for a representative farm comprised of 16 quarter sections that purchased a scraper to conduct drainage relative to performing no drainage

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$126,313	$34,284	$73,734	$188,840	$31,981	$234,948
Yearly Cash Flow With Drainage	$128,633	$35,657	$75,266	$194,369	$31,385	$246,994
Initial Cropland Hectares	902.97	17.41	872.53	930.14	831.77	955.22
Initial Wet Area Hectares	154.80	16.45	128.12	182.14	111.83	230.28
20-year NPV Without Drainage	$1,177,012	$327,708	$693,214	$1,780,608	$317,113	$2,369,834
20-year NPV With Drainage	$1,164,341	$334,130	$671,849	$1,769,244	$285,116	$2,435,004
20-year NPV Difference[a]	-$12,672	$15,770	-$33,048	$15,467	-$70,164	$66,949
20-year NPV Difference per Hectare Drained[a]	-$320	$530	-$976	$182	-$8,298	$712
Percentage of Iterations where 20-year NPV was Positive	17.30%					
Perpetuity NPV Without Drainage[b]	$1,383,930	$364,704	$807,176	$2,054,615	$420,176	$2,677,510
Perpetuity NPV With Drainage[b]	$1,384,513	$376,895	$798,327	$2,083,558	$400,089	$2,775,283
Perpetuity NPV Difference[a, b]	$583	$21,749	-$25,815	$41,127	-$65,406	$101,218
Perpetuity NPV Difference[a, b] per Hectare Drained	-$117	$549	-$776	$485	-$8,012	$1,068
Percentage of Iterations where Perpetuity NPV was Positive	42.60%					
Annual Incentive Payment ($/ha drained)	-$12	$55	-$78	$48	-$801	$107
Wetlands Drained (ha)	54.58	31.61	14.82	115.40	0.00	199.60
Cropped Basins Drained (ha)	10.26	7.94	1.68	25.85	0.00	60.73
Percent of Wet Area Drained on Owned Land	55.35%	20.23%	19.95%	86.43%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	41.63%	15.64%	14.77%	65.47%	0.00%	83.60%
Number Years to Drain a Quarter of Land	3.21	0.25	3.00	3.70	3.00	5.00
PV of Cost of Drainage Conducted[b]	$533	$138	$318	$769	$0	$1,223
Initial Machinery Nuisance Cost Total for Farm[c]	$3,645	$129	$3,494	$3,815	$1,842	$3,903
Initial Input Waste Nuisance Cost Total for Farm[c]	$1,580	$40	$1,516	$1,651	$1,458	$1,689
Initial Nuisance Costs as a percentage of Total Variable Costs	3.35%	0.06%	3.31%	3.44%	2.48%	3.59%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.9 – Summary statistics for a representative farm comprised of 20 quarter sections that purchased a scraper to conduct drainage relative to performing no drainage

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$157,637	$42,778	$91,915	$236,611	$39,618	$298,059
Yearly Cash Flow With Drainage	$161,138	$44,377	$94,540	$242,678	$39,887	$310,952
Initial Cropland Hectares	1,128.62	18.93	1,095.35	1,157.92	1,045.40	1,187.41
Initial Wet Area Hectares	193.62	18.24	164.75	224.62	143.25	277.53
20-year NPV Without Drainage	$1,464,603	$407,605	$861,469	$2,220,741	$402,965	$2,950,910
20-year NPV With Drainage	$1,457,544	$415,997	$842,278	$2,219,270	$377,086	$3,040,452
20-year NPV Difference[a]	-$7,060	$18,350	-$31,341	$26,655	-$54,407	$98,491
20-year NPV Difference per Hectare Drained[a]	-$156	$302	-$661	$246	-$3,211	$801
Percentage of Iterations where 20-year NPV was Positive	29.00%					
Perpetuity NPV Without Drainage[b]	$1,723,093	$453,855	$1,022,790	$2,559,403	$514,266	$3,338,769
Perpetuity NPV With Drainage[b]	$1,733,211	$468,690	$1,018,500	$2,595,450	$501,019	$3,466,898
Perpetuity NPV Difference[a, b]	$10,118	$25,283	-$22,987	$56,736	-$48,767	$148,055
Perpetuity NPV Difference[a, b] per Hectare Drained	$54	$329	-$483	$528	-$2,986	$1,146
Percentage of Iterations where Perpetuity NPV was Positive	60.40%					
Annual Incentive Payment ($/ha drained)	$5	$33	-$48	$53	-$299	$115
Wetlands Drained (ha)	68.64	36.35	24.40	138.33	2.38	236.71
Cropped Basins Drained (ha)	13.06	9.02	3.20	30.18	0.07	66.86
Percent of Wet Area Drained on Owned Land	56.01%	17.95%	25.33%	84.13%	5.49%	98.48%
Percent of Wet Area Drained on Total Land Operated	41.99%	13.82%	18.83%	64.19%	3.98%	77.36%
Number Years to Drain a Quarter of Land	3.32	0.30	3.00	3.86	3.00	5.60
PV of Cost of Drainage Conducted[b]	$522	$119	$342	$722	$200	$1,089
Initial Machinery Nuisance Cost Total for Farm[c]	$5,512	$172	$5,328	$5,721	$2,898	$5,838
Initial Input Waste Nuisance Cost Total for Farm[c]	$2,494	$52	$2,410	$2,583	$2,302	$2,638
Initial Nuisance Costs as a percentage of Total Variable Costs	4.14%	0.06%	4.09%	4.22%	3.12%	4.34%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.10 – Summary statistics for a representative farm comprised of four quarter sections that owned a scraper and conducted additional drainage relative to performing no additional drainage

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$27,813	$8,858	$14,354	$43,331	$3,765	$57,655
Yearly Cash Flow With Drainage	$28,470	$9,140	$14,944	$44,447	$3,765	$59,101
Initial Cropland Hectares	225.59	8.83	210.07	239.44	192.14	245.88
Initial Wet Area Hectares	39.01	8.63	26.02	53.80	16.60	78.71
20-year NPV Without Drainage	$260,895	$84,591	$133,461	$413,684	$28,824	$563,475
20-year NPV With Drainage	$262,608	$85,518	$134,594	$415,402	$28,824	$575,007
20-year NPV Difference[a]	$1,714	$6,215	-$7,325	$13,005	-$27,923	$30,491
20-year NPV Difference per Hectare Drained[a]	$107	$360	-$415	$771	-$1,178	$1,654
Percentage of Iterations where 20-year NPV was Positive	48.50%					
Perpetuity NPV Without Drainage[b]	$306,582	$94,537	$164,019	$478,151	$51,079	$635,314
Perpetuity NPV With Drainage[b]	$310,891	$96,901	$165,488	$482,825	$51,079	$652,516
Perpetuity NPV Difference[a, b]	$4,309	$8,200	-$5,483	$19,961	-$25,291	$47,703
Perpetuity NPV Difference[a, b] per Hectare Drained	$256	$447	-$376	$1,059	-$1,021	$2,083
Percentage of Iterations where Perpetuity NPV was Positive	58.20%					
Annual Incentive Payment ($/ha drained)	$26	$45	-$38	$106	-$102	$208
Wetlands Drained (ha)	11.85	12.93	0.00	29.18	0.00	95.57
Cropped Basins Drained (ha)	2.28	3.46	0.00	7.22	0.00	31.60
Percent of Wet Area Drained on Owned Land	46.75%	33.07%	0.00%	100.00%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	35.17%	25.41%	0.00%	77.48%	0.00%	95.63%
Number Years to Drain a Quarter of Land	3.02	0.11	3.00	3.00	3.00	4.00
PV of Cost of Drainage Conducted[b]	$412	$285	$0	$868	$0	$1,373
Initial Machinery Nuisance Cost Total for Farm[c]	$950	$62	$871	$1,064	$481	$1,332
Initial Input Waste Nuisance Cost Total for Farm[c]	$266	$16	$245	$298	$222	$374
Initial Nuisance Costs as a percentage of Total Variable Costs	2.47%	0.11%	2.42%	2.68%	1.72%	3.41%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.11 – Summary statistics for a representative farm comprised of 12 quarter sections that owned a scraper and conducted additional drainage relative to performing no additional drainage

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$90,433	$25,803	$51,137	$136,137	$20,490	$171,138
Yearly Cash Flow With Drainage	$92,789	$26,748	$52,666	$140,461	$20,686	$182,100
Initial Cropland Hectares	677.22	15.23	651.12	700.91	613.89	720.73
Initial Wet Area Hectares	116.24	14.55	93.44	141.37	79.37	180.95
20-year NPV Without Drainage	$844,417	$247,277	$473,475	$1,287,129	$182,145	$1,733,081
20-year NPV With Drainage	$851,640	$251,651	$473,834	$1,306,973	$173,745	$1,808,975
20-year NPV Difference[a]	$7,223	$12,538	-$10,183	$29,612	-$34,728	$75,894
20-year NPV Difference per Hectare Drained[a]	$140	$247	-$269	$565	-$573	$1,126
Percentage of Iterations where 20-year NPV was Positive	72.00%					
Perpetuity NPV Without Drainage[b]	$992,670	$275,227	$561,543	$1,496,986	$273,537	$1,957,521
Perpetuity NPV With Drainage[b]	$1,008,940	$283,687	$570,729	$1,522,365	$274,430	$2,055,406
Perpetuity NPV Difference[a, b]	$16,271	$17,154	-$4,800	$47,607	-$28,023	$100,671
Perpetuity NPV Difference[a, b] per Hectare Drained	$329	$306	-$149	$839	-$551	$1,531
Percentage of Iterations where Perpetuity NPV was Positive	86.00%					
Annual Incentive Payment ($/ha drained)	$33	$31	-$15	$84	-$55	$153
Wetlands Drained (ha)	39.43	25.64	8.49	91.32	0.00	153.42
Cropped Basins Drained (ha)	7.48	6.64	0.34	21.01	0.00	49.43
Percent of Wet Area Drained on Owned Land	53.13%	22.14%	16.08%	88.59%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	39.98%	17.04%	12.05%	67.04%	0.00%	84.96%
Number Years to Drain a Quarter of Land	3.32	0.39	3.00	4.00	3.00	5.50
PV of Cost of Drainage Conducted[b]	$507	$158	$276	$780	$0	$1,150
Initial Machinery Nuisance Cost Total for Farm[c]	$2,472	$95	$2,352	$2,626	$1,464	$2,766
Initial Input Waste Nuisance Cost Total for Farm[c]	$945	$31	$901	$1,003	$855	$1,059
Initial Nuisance Costs as a percentage of Total Variable Costs	2.85%	0.06%	2.80%	2.97%	2.23%	3.18%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.12 – Summary statistics for a representative farm comprised of 16 quarter sections that owned a scraper and conducted additional drainage relative to performing no additional drainage

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$123,081	$34,300	$70,707	$185,666	$28,696	$231,311
Yearly Cash Flow With Drainage	$126,117	$35,398	$72,760	$191,430	$29,307	$242,386
Initial Cropland Hectares	902.97	17.41	872.53	930.14	831.77	955.22
Initial Wet Area Hectares	154.80	16.45	128.12	182.14	111.83	230.28
20-year NPV Without Drainage	$1,146,751	$327,772	$659,009	$1,739,399	$290,413	$2,334,603
20-year NPV With Drainage	$1,157,642	$333,571	$656,888	$1,769,614	$284,723	$2,388,402
20-year NPV Difference[a]	$10,892	$14,134	-$7,884	$36,551	-$27,473	$73,283
20-year NPV Difference per Hectare Drained[a]	$164	$213	-$171	$531	-$499	$986
Percentage of Iterations where 20-year NPV was Positive	78.10%					
Perpetuity NPV Without Drainage[b]	$1,348,384	$364,794	$776,313	$2,018,981	$384,037	$2,636,128
Perpetuity NPV With Drainage[b]	$1,370,790	$375,093	$787,842	$2,065,951	$388,096	$2,713,765
Perpetuity NPV Difference[a, b]	$22,406	$19,200	-$1,944	$58,043	-$21,538	$111,712
Perpetuity NPV Difference[a, b] per Hectare Drained	$353	$258	-$45	$803	-$412	$1,171
Percentage of Iterations where Perpetuity NPV was Positive	92.20%					
Annual Incentive Payment ($/ha drained)	$35	$26	-$5	$80	-$41	$117
Wetlands Drained (ha)	51.84	31.21	13.83	108.38	0.00	183.75
Cropped Basins Drained (ha)	9.65	7.97	1.27	25.46	0.00	59.53
Percent of Wet Area Drained on Owned Land	52.47%	19.05%	19.70%	83.28%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	39.46%	14.72%	14.44%	62.92%	0.00%	82.53%
Number Years to Drain a Quarter of Land	3.75	0.62	3.00	5.00	3.00	7.00
PV of Cost of Drainage Conducted[b]	$477	$126	$298	$694	$0	$1,179
Initial Machinery Nuisance Cost Total for Farm[c]	$3,645	$129	$3,494	$3,815	$1,842	$3,903
Initial Input Waste Nuisance Cost Total for Farm[c]	$1,580	$40	$1,516	$1,651	$1,458	$1,689
Initial Nuisance Costs as a percentage of Total Variable Costs	3.35%	0.06%	3.31%	3.44%	2.48%	3.59%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.13 – Summary statistics for a representative farm comprised of 20 quarter sections that owned a scraper and conducted additional drainage relative to performing no additional drainage

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$153,603	$42,792	$87,499	$232,274	$35,723	$293,918
Yearly Cash Flow With Drainage	$157,163	$43,883	$90,490	$237,715	$37,199	$304,631
Initial Cropland Hectares	1,128.62	18.93	1,095.35	1,157.92	1,045.40	1,187.41
Initial Wet Area Hectares	193.62	18.24	164.75	224.62	143.25	277.53
20-year NPV Without Drainage	$1,426,827	$407,719	$815,549	$2,186,046	$366,413	$2,902,965
20-year NPV With Drainage	$1,441,795	$413,991	$827,768	$2,198,862	$368,041	$2,936,888
20-year NPV Difference[a]	$14,968	$15,068	-$4,906	$42,675	-$21,949	$96,049
20-year NPV Difference per Hectare Drained[a]	$191	$185	-$87	$516	-$441	$838
Percentage of Iterations where 20-year NPV was Positive	85.40%					
Perpetuity NPV Without Drainage[b]	$1,678,722	$453,989	$977,048	$2,514,041	$471,414	$3,282,453
Perpetuity NPV With Drainage[b]	$1,707,040	$464,530	$988,752	$2,542,509	$482,314	$3,338,805
Perpetuity NPV Difference[a, b]	$28,318	$20,465	$1,276	$66,212	-$20,286	$130,507
Perpetuity NPV Difference[a, b] per Hectare Drained	$375	$227	$31	$771	-$352	$1,276
Percentage of Iterations where Perpetuity NPV was Positive	96.30%					
Annual Incentive Payment ($/ha drained)	$38	$23	$3	$77	-$35	$128
Wetlands Drained (ha)	62.10	35.85	19.75	131.32	2.38	212.10
Cropped Basins Drained (ha)	11.83	9.26	2.52	30.13	0.07	67.48
Percent of Wet Area Drained on Owned Land	50.66%	17.30%	23.32%	80.41%	5.49%	98.48%
Percent of Wet Area Drained on Total Land Operated	37.98%	13.30%	17.04%	61.14%	3.98%	77.36%
Number Years to Drain a Quarter of Land	4.30	0.91	3.14	6.00	3.00	8.75
PV of Cost of Drainage Conducted[b]	$423	$106	$271	$598	$134	$1,014
Initial Machinery Nuisance Cost Total for Farm[c]	$5,512	$172	$5,328	$5,721	$2,898	$5,838
Initial Input Waste Nuisance Cost Total for Farm[c]	$2,494	$52	$2,410	$2,583	$2,302	$2,638
Initial Nuisance Costs as a percentage of Total Variable Costs	4.14%	0.06%	4.09%	4.22%	3.12%	4.34%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.14 – Summary statistics for a representative farm comprised of eight quarter sections that owned a scraper and conducted additional drainage relative to performing no additional drainage with nuisance costs that increased at a constant rate

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$58,784	$17,332	$32,737	$89,559	$11,587	$115,014
Yearly Cash Flow With Drainage	$60,183	$17,857	$33,328	$91,653	$11,587	$118,485
Initial Cropland Hectares	451.61	12.48	429.72	471.60	405.22	482.49
Initial Wet Area Hectares	77.54	12.08	59.22	97.80	43.21	128.62
20-year NPV Without Drainage	$550,182	$166,379	$302,729	$853,137	$99,121	$1,146,555
20-year NPV With Drainage	$554,342	$168,798	$305,482	$853,515	$86,266	$1,192,430
20-year NPV Difference[a]	$4,160	$9,212	-$8,990	$20,213	-$34,764	$55,398
20-year NPV Difference per Hectare Drained[a]	$141	$303	-$331	$690	-$781	$1,346
Percentage of Iterations where 20-year NPV was Positive	64.60%					
Perpetuity NPV Without Drainage[b]	$646,474	$185,315	$368,539	$979,031	$160,852	$1,293,945
Perpetuity NPV With Drainage[b]	$655,979	$190,190	$370,037	$999,096	$150,888	$1,355,200
Perpetuity NPV Difference[a, b]	$9,506	$12,379	-$5,008	$33,107	-$34,131	$66,042
Perpetuity NPV Difference[a, b] per Hectare Drained	$317	$376	-$230	$1,001	-$778	$1,760
Percentage of Iterations where Perpetuity NPV was Positive	77.20%					
Annual Incentive Payment ($/ha drained)	$32	$38	-$23	$100	-$78	$176
Wetlands Drained (ha)	24.11	20.40	0.00	61.87	0.00	125.19
Cropped Basins Drained (ha)	4.65	5.14	0.00	15.27	0.00	40.04
Percent of Wet Area Drained on Owned Land	48.15%	25.96%	0.00%	89.25%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	36.47%	20.08%	0.00%	68.89%	0.00%	85.03%
Number Years to Drain a Quarter of Land	3.19	0.34	3.00	4.00	3.00	5.00
PV of Cost of Drainage Conducted[b]	$482	$210	$0	$818	$0	$1,223
Initial Machinery Nuisance Cost Total for Farm[c]	$1,679	$76	$1,578	$1,801	$907	$1,949
Initial Input Waste Nuisance Cost Total for Farm[c]	$566	$22	$533	$607	$501	$656
Initial Nuisance Costs as a percentage of Total Variable Costs	2.65%	0.07%	2.59%	2.78%	1.99%	3.03%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.15 – Summary statistics for a representative farm comprised of eight quarter sections that owned a scraper and conducted additional drainage relative to performing no additional drainage with no estimate of nuisance costs

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$60,885	$17,263	$35,011	$91,637	$14,110	$117,084
Yearly Cash Flow With Drainage	$61,824	$17,689	$35,630	$93,032	$14,110	$119,632
Initial Cropland Hectares	451.61	12.48	429.72	471.60	405.22	482.49
Initial Wet Area Hectares	77.54	12.08	59.22	97.80	43.21	128.62
20-year NPV Without Drainage	$569,755	$165,752	$321,172	$873,196	$122,599	$1,164,509
20-year NPV With Drainage	$572,070	$167,645	$323,748	$875,889	$122,599	$1,205,573
20-year NPV Difference[a]	$2,315	$7,804	-$8,105	$16,177	-$30,946	$47,021
20-year NPV Difference per Hectare Drained[a]	$81	$282	-$352	$585	-$869	$1,353
Percentage of Iterations where 20-year NPV was Positive	54.80%					
Perpetuity NPV Without Drainage[b]	$669,513	$184,607	$392,927	$1,002,186	$187,457	$1,315,184
Perpetuity NPV With Drainage[b]	$675,606	$188,487	$393,555	$1,010,559	$187,457	$1,369,606
Perpetuity NPV Difference[a, b]	$6,093	$10,405	-$6,421	$27,438	-$37,259	$54,873
Perpetuity NPV Difference[a, b] per Hectare Drained	$216	$350	-$294	$833	-$850	$1,562
Percentage of Iterations where Perpetuity NPV was Positive	66.60%					
Annual Incentive Payment ($/ha drained)	$22	$35	-$29	$83	-$85	$156
Wetlands Drained (ha)	21.11	20.23	0.00	57.50	0.00	126.30
Cropped Basins Drained (ha)	3.82	4.91	0.00	14.08	0.00	37.13
Percent of Wet Area Drained on Owned Land	41.43%	25.73%	0.00%	85.13%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	31.44%	19.93%	0.00%	64.92%	0.00%	85.03%
Number Years to Drain a Quarter of Land	3.13	0.28	3.00	3.67	3.00	5.00
PV of Cost of Drainage Conducted[b]	$403	$211	$0	$726	$0	$1,056
Initial Machinery Nuisance Cost Total for Farm[c]	$0	$0	$0	$0	$0	$0
Initial Input Waste Nuisance Cost Total for Farm[c]	$0	$0	$0	$0	$0	$0
Initial Nuisance Costs as a percentage of Total Variable Costs	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.16 – Summary statistics for a representative farm comprised of 16 quarter sections that owned a scraper and conducted additional drainage relative to performing no additional drainage with nuisance costs that increase at a constant rate

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$123,618	$34,284	$71,318	$186,201	$29,307	$231,840
Yearly Cash Flow With Drainage	$126,552	$35,374	$72,930	$191,830	$29,857	$242,724
Initial Cropland Hectares	902.97	17.41	872.53	930.14	831.77	955.22
Initial Wet Area Hectares	154.80	16.45	128.12	182.14	111.83	230.28
20-year NPV Without Drainage	$1,151,723	$327,641	$664,733	$1,744,279	$296,360	$2,339,731
20-year NPV With Drainage	$1,162,120	$333,366	$661,841	$1,770,989	$289,724	$2,395,424
20-year NPV Difference[a]	$10,397	$13,866	-$8,020	$36,868	-$24,394	$71,680
20-year NPV Difference per Hectare Drained[a]	$158	$212	-$168	$533	-$467	$955
Percentage of Iterations where 20-year NPV was Positive	77.50%					
Perpetuity NPV Without Drainage[b]	$1,354,243	$364,643	$782,120	$2,024,380	$390,475	$2,642,197
Perpetuity NPV With Drainage[b]	$1,375,739	$374,830	$793,291	$2,069,809	$393,958	$2,721,973
Perpetuity NPV Difference[a, b]	$21,496	$18,806	-$2,146	$56,769	-$22,688	$110,073
Perpetuity NPV Difference[a, b] per Hectare Drained	$343	$258	-$53	$804	-$416	$1,159
Percentage of Iterations where Perpetuity NPV was Positive	92.10%					
Annual Incentive Payment ($/ha drained)	$34	$26	-$5	$80	-$42	$116
Wetlands Drained (ha)	51.00	30.97	13.11	108.36	0.00	187.77
Cropped Basins Drained (ha)	9.43	7.92	1.20	25.11	0.00	59.53
Percent of Wet Area Drained on Owned Land	51.56%	19.23%	19.23%	82.87%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	38.78%	14.86%	14.02%	62.92%	0.00%	82.53%
Number Years to Drain a Quarter of Land	3.72	0.61	3.00	5.00	3.00	7.00
PV of Cost of Drainage Conducted[b]	$473	$125	$293	$694	$0	$1,179
Initial Machinery Nuisance Cost Total for Farm[c]	$3,261	$116	$3,128	$3,414	$1,648	$3,495
Initial Input Waste Nuisance Cost Total for Farm[c]	$1,413	$36	$1,356	$1,478	$1,302	$1,511
Initial Nuisance Costs as a percentage of Total Variable Costs	3.02%	0.06%	2.98%	3.10%	2.23%	3.23%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.17 – Summary statistics for a representative farm comprised of 16 quarter sections that owned a scraper and conducted additional drainage relative to performing no additional drainage with no estimate of nuisance costs

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$128,155	$34,162	$75,907	$190,607	$34,482	$236,145
Yearly Cash Flow With Drainage	$130,232	$35,132	$76,975	$195,498	$34,446	$245,950
Initial Cropland Hectares	902.97	17.41	872.53	930.14	831.77	955.22
Initial Wet Area Hectares	154.80	16.45	128.12	182.14	111.83	230.28
20-year NPV Without Drainage	$1,193,731	$326,635	$712,115	$1,787,177	$346,406	$2,380,795
20-year NPV With Drainage	$1,199,696	$331,438	$703,011	$1,802,131	$334,000	$2,434,688
20-year NPV Difference[a]	$5,966	$12,329	-$11,209	$28,989	-$30,480	$64,389
20-year NPV Difference per Hectare Drained[a]	$99	$217	-$253	$466	-$700	$825
Percentage of Iterations where 20-year NPV was Positive	67.90%					
Perpetuity NPV Without Drainage[b]	$1,403,748	$363,481	$833,849	$2,073,201	$444,958	$2,690,808
Perpetuity NPV With Drainage[b]	$1,417,964	$372,387	$836,940	$2,106,151	$442,455	$2,768,550
Perpetuity NPV Difference[a, b]	$14,216	$16,680	-$5,885	$44,783	-$30,478	$90,841
Perpetuity NPV Difference[a, b] per Hectare Drained	$252	$264	-$165	$684	-$602	$1,156
Percentage of Iterations where Perpetuity NPV was Positive	82.20%					
Annual Incentive Payment ($/ha drained)	$25	$26	-$17	$68	-$60	$116
Wetlands Drained (ha)	44.73	30.80	7.99	101.42	0.00	179.89
Cropped Basins Drained (ha)	7.78	7.40	0.26	22.37	0.00	51.26
Percent of Wet Area Drained on Owned Land	44.65%	19.82%	11.74%	76.31%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	33.63%	15.30%	8.86%	58.37%	0.00%	82.53%
Number Years to Drain a Quarter of Land	3.44	0.50	3.00	4.43	3.00	5.63
PV of Cost of Drainage Conducted[b]	$435	$134	$236	$661	$0	$955
Initial Machinery Nuisance Cost Total for Farm[c]	$0	$0	$0	$0	$0	$0
Initial Input Waste Nuisance Cost Total for Farm[c]	$0	$0	$0	$0	$0	$0
Initial Nuisance Costs as a percentage of Total Variable Costs	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.18 - Summary statistics for a representative farm comprised of eight quarter sections that owned a scraper and conducted additional drainage relative to performing no additional drainage that did not participate in the CAIS program

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$50,321	$16,464	$25,646	$79,362	$8,381	$109,706
Yearly Cash Flow With Drainage	$51,570	$16,980	$26,053	$81,098	$8,381	$110,911
Initial Cropland Hectares	451.61	12.48	429.72	471.60	405.22	482.49
Initial Wet Area Hectares	77.54	12.08	59.22	97.80	43.21	128.62
20-year NPV Without Drainage	$475,418	$164,357	$231,228	$777,114	$16,190	$1,017,784
20-year NPV With Drainage	$479,555	$167,061	$231,519	$782,118	$16,190	$1,057,821
20-year NPV Difference[a]	$4,137	$8,403	-$7,009	$18,995	-$33,602	$50,231
20-year NPV Difference per Hectare Drained[a]	$145	$285	-$294	$668	-$755	$1,130
Percentage of Iterations where 20-year NPV was Positive	66.50%					
Perpetuity NPV Without Drainage[b]	$557,724	$182,197	$279,028	$883,356	$73,748	$1,167,148
Perpetuity NPV With Drainage[b]	$566,341	$187,071	$283,128	$903,719	$73,748	$1,222,989
Perpetuity NPV Difference[a, b]	$8,616	$11,223	-$4,824	$30,121	-$28,200	$63,199
Perpetuity NPV Difference[a, b] per Hectare Drained	$300	$354	-$205	$940	-$748	$1,496
Percentage of Iterations where Perpetuity NPV was Positive	76.50%					
Annual Incentive Payment ($/ha drained)	$30	$35	-$21	$94	-$75	$150
Wetlands Drained (ha)	22.76	19.76	0.00	58.97	0.00	108.44
Cropped Basins Drained (ha)	4.36	5.06	0.00	14.94	0.00	40.04
Percent of Wet Area Drained on Owned Land	45.39%	25.61%	0.00%	87.06%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	34.38%	19.80%	0.00%	66.25%	0.00%	85.03%
Number Years to Drain a Quarter of Land	3.18	0.34	3.00	4.00	3.00	5.00
PV of Cost of Drainage Conducted[b]	$468	$215	$0	$811	$0	$1,049
Initial Machinery Nuisance Cost Total for Farm[c]	$1,590	$75	$1,494	$1,720	$880	$1,933
Initial Input Waste Nuisance Cost Total for Farm[c]	$536	$22	$504	$579	$474	$650
Initial Nuisance Costs as a percentage of Total Variable Costs	2.51%	0.08%	2.46%	2.70%	1.94%	2.99%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.19 - Summary statistics for a representative farm comprised of eight quarter sections that purchased a scraper relative to performing no drainage that had a fixed initial land base (Fixed Farm 1)

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$57,087	$16,206	$32,000	$85,918	$12,265	$107,810
Yearly Cash Flow With Drainage	$59,318	$17,209	$33,058	$89,677	$11,947	$116,232
Initial Cropland Hectares	420.43	0.00	420.43	420.43	420.43	420.43
Initial Wet Area Hectares	100.08	0.00	100.08	100.08	100.08	100.08
20-year NPV Without Drainage	$534,461	$155,789	$305,428	$811,505	$120,931	$1,096,890
20-year NPV With Drainage	$532,763	$161,420	$293,137	$815,366	$106,156	$1,132,519
20-year NPV Difference[a]	-$1,698	$9,440	-$15,547	$14,129	-$38,118	$41,804
20-year NPV Difference per Hectare Drained[a]	-$64	$225	-$453	$284	-$751	$706
Percentage of Iterations where 20-year NPV was Positive	41.20%					
Perpetuity NPV Without Drainage[b]	$628,005	$173,341	$361,845	$949,232	$169,095	$1,237,765
Perpetuity NPV With Drainage[b]	$635,110	$182,313	$357,854	$974,910	$154,261	$1,293,005
Perpetuity NPV Difference[a, b]	$7,105	$12,183	-$9,867	$28,535	-$33,176	$61,594
Perpetuity NPV Difference[a, b] per Hectare Drained	$144	$266	-$284	$581	-$761	$1,040
Percentage of Iterations where Perpetuity NPV was Positive	70.00%					
Annual Incentive Payment ($/ha drained)	$14	$27	-$28	$58	-$76	$104
Wetlands Drained (ha)	39.90	12.22	28.06	68.31	28.06	78.48
Cropped Basins Drained (ha)	2.15	0.92	0.79	3.77	0.79	4.65
Percent of Wet Area Drained on Owned Land	63.68%	13.49%	43.69%	89.74%	43.69%	89.74%
Percent of Wet Area Drained on Total Land Operated	42.01%	8.90%	28.83%	59.20%	28.83%	59.20%
Number Years to Drain a Quarter of Land	3.04	0.10	3.00	3.25	3.00	3.80
PV of Cost of Drainage Conducted[b]	$402	$101	$267	$594	$202	$749
Initial Machinery Nuisance Cost Total for Farm[c]	$1,461	$36	$1,464	$1,464	$740	$1,464
Initial Input Waste Nuisance Cost Total for Farm[c]	$492	$0	$492	$492	$492	$492
Initial Nuisance Costs as a percentage of Total Variable Costs	2.48%	0.04%	2.46%	2.51%	1.78%	2.54%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.20 - Summary statistics for a representative farm comprised of eight quarter sections that purchased a scraper relative to performing no drainage that had a fixed initial land base (Fixed Farm 2)

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$62,400	$17,713	$35,270	$93,494	$13,433	$118,248
Yearly Cash Flow With Drainage	$63,275	$18,238	$35,135	$94,947	$12,706	$121,661
Initial Cropland Hectares	460.19	0.00	460.19	460.19	460.19	460.19
Initial Wet Area Hectares	63.01	0.00	63.01	63.01	63.01	63.01
20-year NPV Without Drainage	$584,479	$170,244	$333,958	$887,777	$132,280	$1,199,697
20-year NPV With Drainage	$573,666	$173,554	$314,545	$879,315	$111,712	$1,200,668
20-year NPV Difference[a]	-$10,814	$5,533	-$19,396	-$1,552	-$27,786	$8,194
20-year NPV Difference per Hectare Drained[a]	-$520	$285	-$966	-$61	-$2,006	$239
Percentage of Iterations where 20-year NPV was Positive	2.40%					
Perpetuity NPV Without Drainage[b]	$686,669	$189,418	$396,157	$1,039,429	$186,124	$1,353,056
Perpetuity NPV With Drainage[b]	$680,981	$194,097	$382,989	$1,041,783	$165,628	$1,367,957
Perpetuity NPV Difference[a, b]	-$5,689	$6,776	-$16,170	$5,946	-$23,797	$17,105
Perpetuity NPV Difference[a, b] per Hectare Drained	-$284	$323	-$800	$246	-$1,937	$657
Percentage of Iterations where Perpetuity NPV was Positive	20.50%					
Annual Incentive Payment ($/ha drained)	-$28	$32	-$80	$25	-$194	$66
Wetlands Drained (ha)	20.96	5.09	19.38	31.13	8.77	50.24
Cropped Basins Drained (ha)	1.04	1.38	0.56	4.23	0.26	7.90
Percent of Wet Area Drained on Owned Land	50.88%	11.15%	46.12%	71.76%	20.88%	90.29%
Percent of Wet Area Drained on Total Land Operated	34.92%	7.65%	31.65%	49.25%	14.33%	61.96%
Number Years to Drain a Quarter of Land	3.01	0.06	3.00	3.00	3.00	3.80
PV of Cost of Drainage Conducted[b]	$543	$68	$411	$639	$243	$860
Initial Machinery Nuisance Cost Total for Farm[c]	$1,605	$39	$1,608	$1,608	$812	$1,608
Initial Input Waste Nuisance Cost Total for Farm[c]	$542	$0	$542	$542	$542	$542
Initial Nuisance Costs as a percentage of Total Variable Costs	2.47%	0.04%	2.45%	2.50%	1.77%	2.53%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.21 - Summary statistics for a historical representative farm comprised of four quarter sections that purchased a scraper to conduct drainage relative to performing no drainage

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$47,203	$10,704	$31,583	$65,514	$17,288	$85,076
Yearly Cash Flow With Drainage	$51,204	$12,292	$32,884	$72,782	$19,943	$93,810
Initial Cropland Hectares	197.83	13.35	175.47	219.17	143.19	232.70
Initial Wet Area Hectares	66.77	13.49	46.17	89.28	30.51	124.84
20-year NPV Without Drainage	$442,826	$104,575	$288,448	$629,636	$145,474	$819,973
20-year NPV With Drainage	$441,868	$113,231	$276,166	$644,760	$118,506	$877,576
20-year NPV Difference[a]	-$958	$19,257	-$26,968	$34,959	-$49,909	$93,442
20-year NPV Difference per Hectare Drained[a]	-$89	$454	-$798	$648	-$1,861	$1,472
Percentage of Iterations where 20-year NPV was Positive	39.80%					
Perpetuity NPV Without Drainage[b]	$523,914	$117,815	$345,906	$730,500	$200,253	$932,576
Perpetuity NPV With Drainage[b]	$538,992	$130,048	$343,032	$762,999	$184,334	$982,780
Perpetuity NPV Difference[a, b]	$15,078	$25,117	-$18,194	$60,557	-$38,311	$142,222
Perpetuity NPV Difference[a, b] per Hectare Drained	$258	$530	-$578	$1,143	-$1,575	$1,903
Percentage of Iterations where Perpetuity NPV was Positive	69.20%					
Annual Incentive Payment ($/ha drained)	$26	$53	-$58	$114	-$157	$190
Wetlands Drained (ha)	41.12	20.44	15.01	76.60	0.00	143.00
Cropped Basins Drained (ha)	4.48	4.41	0.44	11.86	0.00	38.11
Percent of Wet Area Drained on Owned Land	89.82%	17.56%	53.06%	100.00%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	67.58%	15.88%	35.57%	86.96%	0.00%	94.22%
Number Years to Drain a Quarter of Land	4.24	0.37	4.00	5.00	4.00	6.00
PV of Cost of Drainage Conducted[b]	$820	$224	$449	$1,158	$0	$1,774
Initial Machinery Nuisance Cost Total for Farm[c]	$906	$138	$693	$1,143	$505	$1,306
Initial Input Waste Nuisance Cost Total for Farm[c]	$261	$40	$201	$329	$168	$378
Initial Nuisance Costs as a percentage of Total Variable Costs	3.12%	0.37%	2.50%	3.74%	2.25%	4.01%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.22 - Summary statistics for a representative farm comprised of eight quarter sections that purchased a scraper to conduct drainage relative to performing no drainage under the assumption that it took four years to complete a drainage project

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$60,240	$17,323	$34,288	$91,141	$12,900	$117,101
Yearly Cash Flow With Drainage	$60,665	$17,695	$34,374	$92,199	$12,900	$117,813
Initial Cropland Hectares	451.61	12.48	429.72	471.60	405.22	482.49
Initial Wet Area Hectares	77.54	12.08	59.22	97.80	43.21	128.62
20-year NPV Without Drainage	$563,818	$166,323	$315,986	$866,559	$115,689	$1,164,078
20-year NPV With Drainage	$552,616	$166,688	$305,798	$856,125	$115,689	$1,171,328
20-year NPV Difference[a]	-$11,202	$8,308	-$23,207	$1,988	-$49,253	$25,631
20-year NPV Difference per Hectare Drained[a]	-$609	$707	-$1,959	$40	-$5,937	$396
Percentage of Iterations where 20-year NPV was Positive	6.30%					
Perpetuity NPV Without Drainage[b]	$662,494	$185,249	$382,269	$995,553	$178,657	$1,314,535
Perpetuity NPV With Drainage[b]	$656,034	$187,967	$373,669	$990,300	$178,657	$1,337,038
Perpetuity NPV Difference[a, b]	-$6,460	$10,277	-$19,790	$13,311	-$52,109	$47,553
Perpetuity NPV Difference[a, b] per Hectare Drained	-$442	$704	-$1,770	$313	-$5,700	$697
Percentage of Iterations where Perpetuity NPV was Positive	19.20%					
Annual Incentive Payment ($/ha drained)	-$44	$70	-$177	$31	-$570	$70
Wetlands Drained (ha)	22.19	20.66	0.00	60.78	0.00	119.02
Cropped Basins Drained (ha)	4.24	5.14	0.00	14.70	0.00	40.04
Percent of Wet Area Drained on Owned Land	44.18%	25.92%	0.00%	87.55%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	33.49%	20.03%	0.00%	67.13%	0.00%	85.03%
Number Years to Drain a Quarter of Land	4.04	0.13	4.00	4.33	4.00	5.00
PV of Cost of Drainage Conducted[b]	$426	$202	$0	$749	$0	$1,058
Initial Machinery Nuisance Cost Total for Farm[c]	$1,590	$75	$1,494	$1,720	$880	$1,933
Initial Input Waste Nuisance Cost Total for Farm[c]	$536	$22	$504	$579	$474	$650
Initial Nuisance Costs as a percentage of Total Variable Costs	2.51%	0.08%	2.46%	2.70%	1.94%	2.99%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.23 - Summary statistics for a representative farm comprised of eight quarter sections that rented a scraper to conduct drainage relative to performing no drainage under low drainage cost assumptions

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$60,240	$17,323	$34,288	$91,141	$12,900	$117,101
Yearly Cash Flow With Drainage	$61,392	$17,748	$34,668	$92,679	$12,900	$119,645
Initial Cropland Hectares	451.61	12.48	429.72	471.60	405.22	482.49
Initial Wet Area Hectares	77.54	12.08	59.22	97.80	43.21	128.62
20-year NPV Without Drainage	$563,818	$166,323	$315,986	$866,559	$115,689	$1,164,078
20-year NPV With Drainage	$567,372	$168,216	$320,872	$870,409	$115,689	$1,204,151
20-year NPV Difference[a]	$3,554	$8,431	-$7,642	$18,321	-$35,073	$50,457
20-year NPV Difference per Hectare Drained[a]	$151	$333	-$345	$772	-$885	$1,446
Percentage of Iterations where 20-year NPV was Positive	60.80%					
Perpetuity NPV Without Drainage[b]	$662,494	$185,249	$382,269	$995,553	$178,657	$1,314,535
Perpetuity NPV With Drainage[b]	$670,225	$189,041	$384,807	$1,004,313	$178,657	$1,369,546
Perpetuity NPV Difference[a, b]	$7,731	$11,095	-$5,569	$29,669	-$30,862	$60,575
Perpetuity NPV Difference[a, b] per Hectare Drained	$321	$412	-$257	$1,046	-$831	$1,728
Percentage of Iterations where Perpetuity NPV was Positive	69.60%					
Annual Incentive Payment ($/ha drained)	$32	$41	-$26	$105	-$83	$173
Wetlands Drained (ha)	18.51	18.01	0.00	52.48	0.00	107.53
Cropped Basins Drained (ha)	3.51	4.69	0.00	12.53	0.00	36.11
Percent of Wet Area Drained on Owned Land	36.72%	24.35%	0.00%	79.74%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	27.83%	18.84%	0.00%	62.28%	0.00%	84.00%
Number Years to Drain a Quarter of Land	3.02	0.09	3.00	3.00	3.00	4.00
PV of Cost of Drainage Conducted[b]	$458	$248	$0	$842	$0	$1,255
Initial Machinery Nuisance Cost Total for Farm[c]	$1,590	$75	$1,494	$1,720	$880	$1,933
Initial Input Waste Nuisance Cost Total for Farm[c]	$536	$22	$504	$579	$474	$650
Initial Nuisance Costs as a percentage of Total Variable Costs	2.51%	0.08%	2.46%	2.70%	1.94%	2.99%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.24 - Summary statistics for a representative farm comprised of eight quarter sections that rented a scraper to conduct drainage relative to performing no drainage under high drainage cost assumptions

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$60,240	$17,323	$34,288	$91,141	$12,900	$117,101
Yearly Cash Flow With Drainage	$60,889	$17,598	$34,615	$92,196	$12,900	$120,569
Initial Cropland Hectares	451.61	12.48	429.72	471.60	405.22	482.49
Initial Wet Area Hectares	77.54	12.08	59.22	97.80	43.21	128.62
20-year NPV Without Drainage	$563,818	$166,323	$315,986	$866,559	$115,689	$1,164,078
20-year NPV With Drainage	$565,290	$167,605	$319,012	$870,689	$115,689	$1,213,950
20-year NPV Difference[a]	$1,472	$5,728	-$6,373	$11,496	-$22,664	$49,872
20-year NPV Difference per Hectare Drained[a]	$82	$307	-$375	$624	-$972	$1,792
Percentage of Iterations where 20-year NPV was Positive	43.00%					
Perpetuity NPV Without Drainage[b]	$662,494	$185,249	$382,269	$995,553	$178,657	$1,314,535
Perpetuity NPV With Drainage[b]	$666,383	$187,654	$385,273	$1,003,070	$178,657	$1,373,925
Perpetuity NPV Difference[a, b]	$3,889	$7,872	-$5,569	$18,453	-$27,503	$59,390
Perpetuity NPV Difference[a, b] per Hectare Drained	$223	$405	-$328	$960	-$888	$2,134
Percentage of Iterations where Perpetuity NPV was Positive	54.00%					
Annual Incentive Payment ($/ha drained)	$22	$41	-$33	$96	-$89	$213
Wetlands Drained (ha)	10.04	12.26	0.00	27.92	0.00	84.79
Cropped Basins Drained (ha)	2.25	3.82	0.00	11.37	0.00	29.06
Percent of Wet Area Drained on Owned Land	20.88%	18.97%	0.00%	54.94%	0.00%	90.41%
Percent of Wet Area Drained on Total Land Operated	15.78%	14.45%	0.00%	42.02%	0.00%	74.53%
Number Years to Drain a Quarter of Land	3.01	0.08	3.00	3.00	3.00	4.00
PV of Cost of Drainage Conducted[b]	$415	$318	$0	$870	$0	$1,308
Initial Machinery Nuisance Cost Total for Farm[c]	$1,590	$75	$1,494	$1,720	$880	$1,933
Initial Input Waste Nuisance Cost Total for Farm[c]	$536	$22	$504	$579	$474	$650
Initial Nuisance Costs as a percentage of Total Variable Costs	2.51%	0.08%	2.46%	2.70%	1.94%	2.99%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.25 – Summary statistics for a representative farm comprised of eight quarter sections that purchased a scraper to conduct drainage relative to performing no drainage under the assumption that yields in cropped basins would be 0 tonnes/ha 2 years out of 10

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$61,199	$17,459	$34,849	$92,587	$13,000	$119,499
Yearly Cash Flow With Drainage	$61,620	$17,884	$34,929	$93,796	$13,000	$120,390
Initial Cropland Hectares	451.61	12.48	429.72	471.60	405.22	482.49
Initial Wet Area Hectares	77.54	12.08	59.22	97.80	43.21	128.62
20-year NPV Without Drainage	$572,725	$167,784	$320,756	$876,481	$120,562	$1,179,331
20-year NPV With Drainage	$560,957	$168,908	$308,683	$861,812	$120,562	$1,200,802
20-year NPV Difference[a]	-$11,768	$8,852	-$24,904	$346	-$52,011	$26,826
20-year NPV Difference per Hectare Drained[a]	-$608	$698	-$1,853	$8	-$6,309	$519
Percentage of Iterations where 20-year NPV was Positive	5.40%					
Perpetuity NPV Without Drainage[b]	$673,009	$186,773	$392,840	$1,008,895	$179,747	$1,331,285
Perpetuity NPV With Drainage[b]	$665,908	$190,219	$378,484	$1,007,638	$179,747	$1,366,895
Perpetuity NPV Difference[a, b]	-$7,101	$10,772	-$20,860	$12,269	-$46,381	$42,192
Perpetuity NPV Difference[a, b] per Hectare Drained	-$455	$709	-$1,733	$281	-$6,145	$768
Percentage of Iterations where Perpetuity NPV was Positive	18.30%					
Annual Incentive Payment ($/ha drained)	-$46	$71	-$173	$28	-$614	$77
Wetlands Drained (ha)	23.63	20.18	0.00	60.45	0.00	119.02
Cropped Basins Drained (ha)	4.28	5.00	0.00	14.56	0.00	37.13
Percent of Wet Area Drained on Owned Land	46.61%	25.93%	0.00%	88.36%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	35.34%	20.11%	0.00%	67.18%	0.00%	85.03%
Number Years to Drain a Quarter of Land	3.10	0.23	3.00	3.50	3.00	4.50
PV of Cost of Drainage Conducted[b]	$477	$215	$0	$819	$0	$1,069
Initial Machinery Nuisance Cost Total for Farm[c]	$1,590	$75	$1,494	$1,720	$880	$1,933
Initial Input Waste Nuisance Cost Total for Farm[c]	$536	$22	$504	$579	$474	$650
Initial Nuisance Costs as a percentage of Total Variable Costs	2.51%	0.08%	2.46%	2.70%	1.94%	2.99%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.26 – Summary statistics for a representative farm comprised of eight quarter sections that purchased a scraper to conduct drainage relative to performing no drainage under the assumption that yields in cropped basins would be 0 tonnes/ha 6 years out of 10

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$59,300	$17,224	$33,524	$89,571	$12,515	$115,776
Yearly Cash Flow With Drainage	$60,127	$17,797	$33,608	$91,774	$12,515	$119,310
Initial Cropland Hectares	451.61	12.48	429.72	471.60	405.22	482.49
Initial Wet Area Hectares	77.54	12.08	59.22	97.80	43.21	128.62
20-year NPV Without Drainage	$555,092	$165,497	$308,858	$856,034	$95,756	$1,153,661
20-year NPV With Drainage	$545,640	$167,306	$297,981	$848,923	$95,756	$1,187,422
20-year NPV Difference[a]	-$9,452	$9,857	-$22,747	$6,773	-$51,506	$49,209
20-year NPV Difference per Hectare Drained[a]	-$510	$684	-$1,775	$184	-$5,755	$783
Percentage of Iterations where 20-year NPV was Positive	12.00%					
Perpetuity NPV Without Drainage[b]	$652,214	$184,284	$375,522	$983,878	$158,679	$1,302,227
Perpetuity NPV With Drainage[b]	$648,585	$188,956	$360,806	$987,921	$158,679	$1,352,816
Perpetuity NPV Difference[a, b]	-$3,629	$12,862	-$19,618	$20,132	-$45,132	$59,857
Perpetuity NPV Difference[a, b] per Hectare Drained	-$324	$694	-$1,628	$481	-$5,447	$1,061
Percentage of Iterations where Perpetuity NPV was Positive	28.20%					
Annual Incentive Payment ($/ha drained)	-$32	$69	-$163	$48	-$545	$106
Wetlands Drained (ha)	24.59	20.25	0.00	60.69	0.00	125.19
Cropped Basins Drained (ha)	4.96	5.32	0.00	15.51	0.00	40.04
Percent of Wet Area Drained on Owned Land	49.57%	26.33%	0.00%	90.37%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	37.52%	20.35%	0.00%	70.73%	0.00%	85.03%
Number Years to Drain a Quarter of Land	3.11	0.22	3.00	3.60	3.00	4.00
PV of Cost of Drainage Conducted[b]	$495	$212	$0	$835	$0	$1,263
Initial Machinery Nuisance Cost Total for Farm[c]	$1,590	$75	$1,494	$1,720	$880	$1,933
Initial Input Waste Nuisance Cost Total for Farm[c]	$536	$22	$504	$579	$474	$650
Initial Nuisance Costs as a percentage of Total Variable Costs	2.51%	0.08%	2.46%	2.70%	1.94%	2.99%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.27 - Summary statistics for a representative farm comprised of eight quarter sections that owned a scraper and conducted additional drainage relative to performing no additional drainage under the assumption that there was a 5% yield advantage in drained areas

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$59,827	$17,435	$33,562	$91,216	$12,428	$116,656
Yearly Cash Flow With Drainage	$61,436	$18,022	$34,268	$93,117	$12,428	$120,457
Initial Cropland Hectares	451.61	12.48	429.72	471.60	405.22	482.49
Initial Wet Area Hectares	77.54	12.08	59.22	97.80	43.21	128.62
20-year NPV Without Drainage	$559,867	$167,415	$310,088	$867,197	$105,074	$1,160,313
20-year NPV With Drainage	$565,386	$170,266	$313,411	$872,005	$93,879	$1,210,803
20-year NPV Difference[a]	$5,519	$9,845	-$7,580	$23,035	-$34,263	$60,702
20-year NPV Difference per Hectare Drained[a]	$184	$316	-$299	$774	-$770	$1,414
Percentage of Iterations where 20-year NPV was Positive	68.50%					
Perpetuity NPV Without Drainage[b]	$657,900	$186,456	$377,356	$995,155	$167,950	$1,309,926
Perpetuity NPV With Drainage[b]	$669,311	$191,954	$383,510	$1,014,179	$160,084	$1,376,887
Perpetuity NPV Difference[a, b]	$11,411	$13,433	-$4,536	$37,250	-$27,749	$72,247
Perpetuity NPV Difference[a, b] per Hectare Drained	$377	$394	-$195	$1,086	-$738	$1,845
Percentage of Iterations where Perpetuity NPV was Positive	80.00%					
Annual Incentive Payment ($/ha drained)	$38	$39	-$19	$109	-$74	$185
Wetlands Drained (ha)	24.34	20.45	0.00	60.82	0.00	125.19
Cropped Basins Drained (ha)	4.67	5.22	0.00	15.32	0.00	40.04
Percent of Wet Area Drained on Owned Land	48.53%	26.04%	0.00%	89.25%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	36.76%	20.17%	0.00%	69.22%	0.00%	85.03%
Number Years to Drain a Quarter of Land	3.21	0.35	3.00	4.00	3.00	5.00
PV of Cost of Drainage Conducted[b]	$482	$210	$0	$818	$0	$1,049
Initial Machinery Nuisance Cost Total for Farm[c]	$1,590	$75	$1,494	$1,720	$880	$1,933
Initial Input Waste Nuisance Cost Total for Farm[c]	$536	$22	$504	$579	$474	$650
Initial Nuisance Costs as a percentage of Total Variable Costs	2.51%	0.08%	2.46%	2.70%	1.94%	2.99%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.28 - Summary statistics for a representative farm comprised of eight quarter sections that owned a scraper and conducted additional drainage relative to performing no additional drainage under the assumption that there was a 10% yield advantage in drained areas

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$60,759	$17,546	$34,285	$92,349	$13,131	$118,188
Yearly Cash Flow With Drainage	$62,594	$18,199	$35,107	$94,705	$13,131	$122,381
Initial Cropland Hectares	451.61	12.48	429.72	471.60	405.22	482.49
Initial Wet Area Hectares	77.54	12.08	59.22	97.80	43.21	128.62
20-year NPV Without Drainage	$568,523	$168,521	$316,258	$875,537	$109,719	$1,173,273
20-year NPV With Drainage	$575,500	$171,798	$320,425	$886,529	$100,246	$1,228,695
20-year NPV Difference[a]	$6,977	$10,628	-$6,485	$25,512	-$33,698	$66,414
20-year NPV Difference per Hectare Drained[a]	$228	$330	-$264	$813	-$757	$1,494
Percentage of Iterations where 20-year NPV was Positive	72.10%					
Perpetuity NPV Without Drainage[b]	$668,113	$187,679	$386,071	$1,007,493	$173,576	$1,324,934
Perpetuity NPV With Drainage[b]	$681,576	$193,801	$394,175	$1,028,394	$167,881	$1,398,026
Perpetuity NPV Difference[a, b]	$13,463	$14,617	-$3,974	$42,162	-$26,578	$78,960
Perpetuity NPV Difference[a, b] per Hectare Drained	$437	$414	-$169	$1,163	-$730	$1,944
Percentage of Iterations where Perpetuity NPV was Positive	83.70%					
Annual Incentive Payment ($/ha drained)	$44	$41	-$17	$116	-$73	$194
Wetlands Drained (ha)	24.75	20.49	0.00	62.06	0.00	125.19
Cropped Basins Drained (ha)	4.75	5.23	0.00	15.50	0.00	40.04
Percent of Wet Area Drained on Owned Land	49.38%	26.02%	0.00%	89.97%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	37.39%	20.13%	0.00%	69.89%	0.00%	86.26%
Number Years to Drain a Quarter of Land	3.22	0.36	3.00	4.00	3.00	5.00
PV of Cost of Drainage Conducted[b]	$489	$211	$0	$830	$0	$1,223
Initial Machinery Nuisance Cost Total for Farm[c]	$1,590	$75	$1,494	$1,720	$880	$1,933
Initial Input Waste Nuisance Cost Total for Farm[c]	$536	$22	$504	$579	$474	$650
Initial Nuisance Costs as a percentage of Total Variable Costs	2.51%	0.08%	2.46%	2.70%	1.94%	2.99%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.29 - Summary statistics for a representative farm comprised of eight quarter sections that followed a canola-barley-flax-wheat rotation, owned a scraper and conducted additional drainage relative to performing no additional drainage

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$75,022	$21,525	$41,898	$113,786	$16,033	$145,673
Yearly Cash Flow With Drainage	$77,213	$22,412	$43,135	$117,285	$16,033	$151,436
Initial Cropland Hectares	451.61	12.48	429.72	471.60	405.22	482.49
Initial Wet Area Hectares	77.54	12.08	59.22	97.80	43.21	128.62
20-year NPV Without Drainage	$696,885	$204,930	$389,930	$1,065,735	$149,214	$1,432,913
20-year NPV With Drainage	$704,085	$209,382	$393,757	$1,079,287	$135,342	$1,487,977
20-year NPV Difference[a]	$7,200	$12,438	-$9,951	$29,173	-$27,351	$64,144
20-year NPV Difference per Hectare Drained[a]	$180	$327	-$328	$771	-$811	$1,390
Percentage of Iterations where 20-year NPV was Positive	70.30%					
Perpetuity NPV Without Drainage[b]	$819,958	$228,413	$464,505	$1,232,676	$217,623	$1,618,874
Perpetuity NPV With Drainage[b]	$835,465	$236,439	$473,404	$1,253,890	$217,623	$1,693,880
Perpetuity NPV Difference[a, b]	$15,507	$16,930	-$6,059	$45,998	-$28,014	$90,626
Perpetuity NPV Difference[a, b] per Hectare Drained	$402	$399	-$220	$1,100	-$836	$1,655
Percentage of Iterations where Perpetuity NPV was Positive	84.30%					
Annual Incentive Payment ($/ha drained)	$40	$40	-$22	$110	-$84	$166
Wetlands Drained (ha)	30.59	21.31	6.14	71.37	0.00	135.89
Cropped Basins Drained (ha)	5.85	5.69	0.15	17.48	0.00	42.21
Percent of Wet Area Drained on Owned Land	61.29%	24.54%	17.34%	100.00%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	46.39%	19.09%	12.32%	74.95%	0.00%	89.65%
Number Years to Drain a Quarter of Land	3.57	0.61	3.00	4.75	3.00	9.00
PV of Cost of Drainage Conducted[b]	$579	$206	$280	$913	$0	$1,480
Initial Machinery Nuisance Cost Total for Farm[c]	$1,762	$82	$1,656	$1,898	$944	$2,116
Initial Input Waste Nuisance Cost Total for Farm[c]	$629	$25	$591	$676	$562	$763
Initial Nuisance Costs as a percentage of Total Variable Costs	2.45%	0.07%	2.40%	2.62%	1.84%	2.87%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.30 - Summary statistics for a representative farm comprised of eight quarter sections that followed a canola-wheat-summerfallow rotation, owned a scraper and conducted additional drainage relative to performing no additional drainage

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$52,242	$15,598	$28,721	$79,604	$10,713	$109,259
Yearly Cash Flow With Drainage	$53,279	$15,966	$29,074	$81,723	$10,713	$111,274
Initial Cropland Hectares	451.61	12.48	429.72	471.60	405.22	482.49
Initial Wet Area Hectares	77.54	12.08	59.22	97.80	43.21	128.62
20-year NPV Without Drainage	$486,577	$146,752	$265,980	$752,285	$63,908	$1,014,918
20-year NPV With Drainage	$489,508	$148,442	$266,746	$754,787	$63,908	$1,036,052
20-year NPV Difference[a]	$2,930	$7,647	-$7,368	$15,743	-$28,917	$39,601
20-year NPV Difference per Hectare Drained[a]	$113	$280	-$320	$636	-$942	$1,052
Percentage of Iterations where 20-year NPV was Positive	61.20%					
Perpetuity NPV Without Drainage[b]	$573,085	$164,285	$326,135	$866,901	$111,838	$1,155,426
Perpetuity NPV With Drainage[b]	$579,955	$167,789	$329,808	$877,347	$111,838	$1,190,702
Perpetuity NPV Difference[a, b]	$6,870	$10,093	-$5,497	$25,937	-$27,625	$60,575
Perpetuity NPV Difference[a, b] per Hectare Drained	$261	$349	-$271	$857	-$900	$1,407
Percentage of Iterations where Perpetuity NPV was Positive	72.60%					
Annual Incentive Payment ($/ha drained)	$26	$35	-$27	$86	-$90	$141
Wetlands Drained (ha)	20.79	19.67	0.00	55.60	0.00	119.02
Cropped Basins Drained (ha)	3.99	4.95	0.00	14.47	0.00	36.47
Percent of Wet Area Drained on Owned Land	41.38%	25.39%	0.00%	84.91%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	31.37%	19.59%	0.00%	65.00%	0.00%	85.03%
Number Years to Drain a Quarter of Land	3.10	0.25	3.00	3.67	3.00	4.50
PV of Cost of Drainage Conducted[b]	$423	$207	$0	$740	$0	$1,035
Initial Machinery Nuisance Cost Total for Farm[c]	$1,420	$77	$1,330	$1,546	$754	$1,747
Initial Input Waste Nuisance Cost Total for Farm[c]	$499	$22	$467	$542	$439	$614
Initial Nuisance Costs as a percentage of Total Variable Costs	2.47%	0.09%	2.42%	2.68%	1.77%	2.90%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.31 – Summary statistics for a representative farm comprised of eight quarter sections that purchased a scraper to conduct drainage relative to performing no drainage using 2002 commodity prices as the means of the price distributions each year over the 20-year simulation period

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$69,446	$18,503	$41,510	$102,324	$19,261	$130,360
Yearly Cash Flow With Drainage	$70,432	$19,191	$41,558	$104,515	$19,261	$133,254
Initial Cropland Hectares	451.61	12.48	429.72	471.60	405.22	482.49
Initial Wet Area Hectares	77.54	12.08	59.22	97.80	43.21	128.62
20-year NPV Without Drainage	$649,666	$178,438	$382,771	$975,124	$177,819	$1,289,531
20-year NPV With Drainage	$639,794	$180,849	$372,070	$961,109	$148,382	$1,325,861
20-year NPV Difference[a]	-$9,872	$10,575	-$24,863	$8,196	-$52,335	$42,516
20-year NPV Difference per Hectare Drained[a]	-$483	$641	-$1,708	$197	-$5,919	$762
Percentage of Iterations where 20-year NPV was Positive	12.40%					
Perpetuity NPV Without Drainage[b]	$763,908	$198,597	$461,774	$1,119,968	$250,958	$1,457,219
Perpetuity NPV With Drainage[b]	$760,787	$204,228	$452,746	$1,129,281	$230,225	$1,510,880
Perpetuity NPV Difference[a, b]	-$3,120	$14,038	-$20,694	$23,515	-$45,455	$65,427
Perpetuity NPV Difference[a, b] per Hectare Drained	-$288	$664	-$1,549	$505	-$5,651	$1,125
Percentage of Iterations where Perpetuity NPV was Positive	30.70%					
Annual Incentive Payment ($/ha drained)	-$29	$66	-$155	$50	-$565	$113
Wetlands Drained (ha)	27.38	20.62	1.47	63.24	0.00	118.06
Cropped Basins Drained (ha)	5.20	5.27	0.04	15.91	0.00	40.04
Percent of Wet Area Drained on Owned Land	54.61%	26.23%	11.71%	95.57%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	41.34%	20.31%	8.24%	72.93%	0.00%	86.26%
Number Years to Drain a Quarter of Land	3.15	0.27	3.00	3.67	3.00	4.67
PV of Cost of Drainage Conducted[b]	$540	$214	$195	$866	$0	$1,413
Initial Machinery Nuisance Cost Total for Farm[c]	$1,590	$75	$1,494	$1,720	$880	$1,933
Initial Input Waste Nuisance Cost Total for Farm[c]	$536	$22	$504	$579	$474	$650
Initial Nuisance Costs as a percentage of Total Variable Costs	2.51%	0.08%	2.45%	2.69%	1.93%	2.98%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.32 – Summary statistics for a representative farm comprised of eight quarter sections that purchased a scraper to conduct drainage relative to performing no drainage using 5-year average (1998-2002) commodity prices as the means of the price distributions each year over the 20-year simulation period

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$51,005	$16,370	$25,985	$79,837	$5,897	$104,249
Yearly Cash Flow With Drainage	$51,287	$16,731	$26,036	$80,800	$5,897	$106,195
Initial Cropland Hectares	451.61	12.48	429.72	471.60	405.22	482.49
Initial Wet Area Hectares	77.54	12.08	59.22	97.80	43.21	128.62
20-year NPV Without Drainage	$476,465	$157,202	$243,150	$759,822	$47,105	$1,039,794
20-year NPV With Drainage	$465,546	$157,798	$230,056	$746,988	$47,105	$1,062,240
20-year NPV Difference[a]	-$10,918	$8,157	-$23,185	$39	-$42,456	$29,958
20-year NPV Difference per Hectare Drained[a]	-$624	$737	-$1,955	$2	-$6,055	$631
Percentage of Iterations where 20-year NPV was Positive	5.10%					
Perpetuity NPV Without Drainage[b]	$560,360	$175,091	$291,080	$873,364	$99,500	$1,171,750
Perpetuity NPV With Drainage[b]	$553,427	$177,799	$281,456	$872,115	$99,500	$1,207,738
Perpetuity NPV Difference[a, b]	-$6,933	$9,610	-$20,195	$9,560	-$44,195	$39,791
Perpetuity NPV Difference[a, b] per Hectare Drained	-$478	$729	-$1,838	$254	-$5,833	$764
Percentage of Iterations where Perpetuity NPV was Positive	17.20%					
Annual Incentive Payment ($/ha drained)	-$48	$73	-$184	$25	-$583	$76
Wetlands Drained (ha)	20.93	19.62	0.00	56.27	0.00	114.96
Cropped Basins Drained (ha)	4.04	5.02	0.00	14.37	0.00	37.13
Percent of Wet Area Drained on Owned Land	41.73%	25.67%	0.00%	85.44%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	31.62%	19.83%	0.00%	65.11%	0.00%	85.03%
Number Years to Drain a Quarter of Land	3.07	0.19	3.00	3.50	3.00	4.00
PV of Cost of Drainage Conducted[b]	$419	$206	$0	$735	$0	$1,080
Initial Machinery Nuisance Cost Total for Farm[c]	$1,590	$75	$1,494	$1,720	$880	$1,933
Initial Input Waste Nuisance Cost Total for Farm[c]	$536	$22	$504	$579	$474	$650
Initial Nuisance Costs as a percentage of Total Variable Costs	2.52%	0.08%	2.47%	2.71%	1.95%	3.00%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.33 – Summary statistics for a representative farm comprised of eight quarter sections that purchased a scraper to conduct drainage relative to performing no drainage using an 8% discount rate

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$60,240	$17,323	$34,288	$91,141	$12,900	$117,101
Yearly Cash Flow With Drainage	$60,881	$17,917	$34,350	$92,410	$12,900	$119,864
Initial Cropland Hectares	451.61	12.48	429.72	471.60	405.22	482.49
Initial Wet Area Hectares	77.54	12.08	59.22	97.80	43.21	128.62
20-year NPV Without Drainage	$638,574	$185,892	$359,997	$977,377	$142,773	$1,304,307
20-year NPV With Drainage	$629,037	$188,960	$346,422	$970,095	$111,323	$1,343,046
20-year NPV Difference[a]	-$9,536	$11,638	-$25,965	$11,537	-$50,673	$49,216
20-year NPV Difference per Hectare Drained[a]	-$468	$648	-$1,728	$259	-$5,792	$812
Percentage of Iterations where 20-year NPV was Positive	15.80%					
Perpetuity NPV Without Drainage[b]	$813,369	$227,226	$467,438	$1,211,772	$218,560	$1,570,829
Perpetuity NPV With Drainage[b]	$814,602	$235,581	$453,004	$1,230,683	$213,918	$1,636,470
Perpetuity NPV Difference[a, b]	$1,233	$18,422	-$22,709	$35,615	-$45,885	$90,370
Perpetuity NPV Difference[a, b] per Hectare Drained	-$166	$720	-$1,489	$793	-$5,379	$1,416
Percentage of Iterations where Perpetuity NPV was Positive	42.40%					
Annual Incentive Payment ($/ha drained)	-$13	$58	-$119	$63	-$430	$113
Wetlands Drained (ha)	28.38	20.69	3.43	65.14	0.00	119.84
Cropped Basins Drained (ha)	5.42	5.36	0.07	16.40	0.00	40.04
Percent of Wet Area Drained on Owned Land	56.70%	25.98%	12.81%	100.00%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	42.94%	20.17%	9.36%	74.30%	0.00%	86.26%
Number Years to Drain a Quarter of Land	3.16	0.28	3.00	3.67	3.00	4.67
PV of Cost of Drainage Conducted[b]	$607	$222	$296	$953	$0	$1,437
Initial Machinery Nuisance Cost Total for Farm[c]	$1,590	$75	$1,494	$1,720	$880	$1,933
Initial Input Waste Nuisance Cost Total for Farm[c]	$536	$22	$504	$579	$474	$650
Initial Nuisance Costs as a percentage of Total Variable Costs	2.51%	0.08%	2.46%	2.70%	1.94%	2.99%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.

Table L.34 – Summary statistics for a representative farm comprised of eight quarter sections that purchased a scraper to conduct drainage relative to performing no drainage using a 12% discount rate

	Mean	Std Dev	5% Level	95% Level	Minimum	Maximum
Yearly Cash Flow Without Drainage	$60,240	$17,323	$34,288	$91,141	$12,900	$117,101
Yearly Cash Flow With Drainage	$60,820	$17,775	$34,408	$91,949	$12,900	$119,686
Initial Cropland Hectares	451.61	12.48	429.72	471.60	405.22	482.49
Initial Wet Area Hectares	77.54	12.08	59.22	97.80	43.21	128.62
20-year NPV Without Drainage	$503,494	$150,811	$275,443	$779,404	$95,301	$1,047,686
20-year NPV With Drainage	$492,538	$151,502	$260,949	$767,159	$95,301	$1,070,360
20-year NPV Difference[a]	-$10,956	$7,764	-$22,614	$0	-$38,824	$29,025
20-year NPV Difference per Hectare Drained[a]	-$638	$745	-$1,957	$0	-$6,132	$577
Percentage of Iterations where 20-year NPV was Positive	3.90%					
Perpetuity NPV Without Drainage[b]	$561,885	$159,889	$324,762	$854,597	$133,510	$1,136,719
Perpetuity NPV With Drainage[b]	$553,686	$161,835	$314,000	$849,364	$133,510	$1,168,380
Perpetuity NPV Difference[a, b]	-$8,199	$8,321	-$20,026	$5,404	-$39,136	$35,154
Perpetuity NPV Difference[a, b] per Hectare Drained	-$536	$734	-$1,873	$132	-$5,994	$664
Percentage of Iterations where Perpetuity NPV was Positive	11.00%					
Annual Incentive Payment ($/ha drained)	-$64	$88	-$225	$16	-$719	$80
Wetlands Drained (ha)	20.54	19.16	0.00	55.37	0.00	105.87
Cropped Basins Drained (ha)	3.94	4.93	0.00	13.96	0.00	37.13
Percent of Wet Area Drained on Owned Land	40.91%	25.26%	0.00%	84.64%	0.00%	100.00%
Percent of Wet Area Drained on Total Land Operated	31.00%	19.52%	0.00%	64.54%	0.00%	85.03%
Number Years to Drain a Quarter of Land	3.06	0.18	3.00	3.50	3.00	4.00
PV of Cost of Drainage Conducted[b]	$398	$200	$0	$693	$0	$958
Initial Machinery Nuisance Cost Total for Farm[c]	$1,590	$75	$1,494	$1,720	$880	$1,933
Initial Input Waste Nuisance Cost Total for Farm[c]	$536	$22	$504	$579	$474	$650
Initial Nuisance Costs as a percentage of Total Variable Costs	2.51%	0.08%	2.46%	2.70%	1.94%	2.99%

Notes: [a] Differences were calculated by subtracting the NPV for the situation where the farm operator did not conduct drainage from the NPV where the farm operator conducted drainage. [b] Perpetuity NPVs were calculated taking into account expected cash flows that occur beyond the 20-year simulation period. [c] PV of drainage costs was the sum of all costs associated with draining a hectare of land discounted to a present value. [d] Initial nuisance costs were costs associated with maneuvering around wetlands before any drainage was conducted.